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GUEST SPEAKER'S ADDRESS

LAKE SYSTEMS. WESTERN VICTORIA

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INTRODUCTION

Lakes occur in the south west portion of Victoria from Ballarat to the ocean in the south, and west to the South Australian border (Fig. 1). The lake systems are in definite patterns which depend on the geological history of the area.

The age of the lake formations can be determined by studying the geology and geomorphology of the areas and by dating carbon in the lake sediments. Raised terraces surrounding the lakes indicate changes in climate in the past, and lacustrine sediment studies have revealed the climatic history over the past 20,000 years.

The lakes vary in size from a few acres to one hundred square miles and in depth from a few feet to over 200 feet. Water levels vary seasonally and drying out is not uncommon in the smaller lakes during the summer or in times of drought. However, the larger lakes have not been dry during recorded history.

The quality of the lake waters varies from 100 p.p.m. T.D.S., useful for stock and domestic purposes, to salinities greater than that of sea water. The hydrology of the various catchments indicates that the cyclic salt contribution to the lakes and stream waters is less than 10%.

A. LAKE SYSTEMS

In western Victoria there are five major geological environments in which the lakes can be grouped. These environments are:-

1. Strand line dune
2. Former river valley
3. Limestone
4. Lava field
5. Maar

1. Strand line dune

During the Tertiary Period the sea encroached eastwards into Victoria to beyond Mildura in the Mallee, beyond the Arapiles in the Wimmera and beyond Lake Bolac in the Western District. Marine sedimentary beds were deposited over the area during the Pliocene to the Pleistocene as the sea receded.

Blackburn (1962a) demonstrated that the limit of the last sea invasion is marked by coastal dunes formed along its shore-line, and at each stillstand of the sea a dune was formed. These dunes remain as topographic features on the plains.

Mount Arapiles, near Horsham, was surrounded by the sea during the period of marine invasion. The eastern edge of Mount Arapiles can be identified as a sea cliff with offshore rock stacks and wave-cut platforms indicating the former sea level.

The oldest strand line dunes are furthest inland and the younger dunes are evident towards the present coast. Boutakoff (1963) stated that the dunes nearer the present coast were formed during the Lower to Upper Pleistocene.

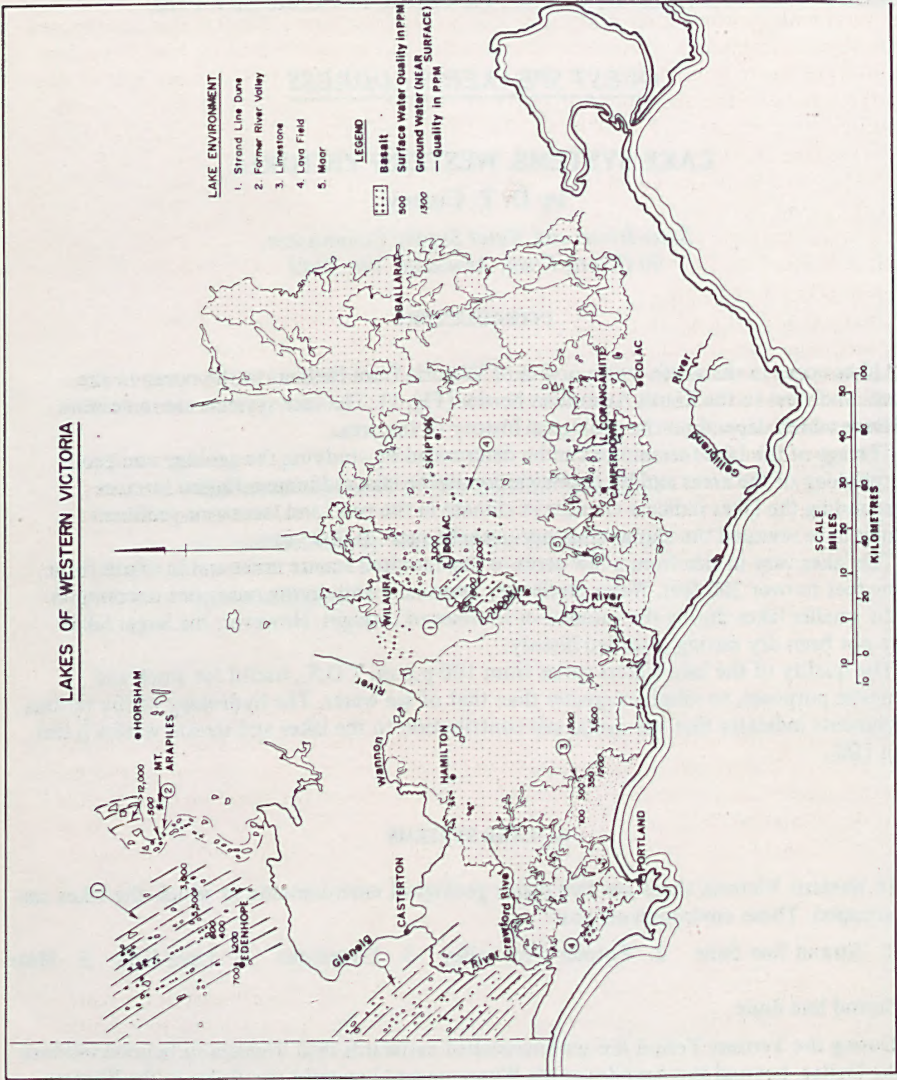


Fig. 1. Locality plan of lake environments. Salinities of surface and ground water.

Generally the Tertiary sea bed sediments are composed of thick sequences of limestone except along the edges of the former sea where limestones are interbedded with sandstone.

The strand line dunes controlled the land surface drainage. The run-off water was concentrated in the hollows (swales) between the dunes, resulting in the formation of parallel strings of rounded lakes.

It would be possible for lakes to form as soon as the sea receded providing the climatic conditions were favourable and either the bed materials were impermeable or the water table intersected the surface.

Permeable limestone underlies the area south of the Little Desert and west into South Australia and lakes in these areas are dependent on groundwater. Seasonal rainfalls control the groundwater level, so that lake beds at lower elevations are below the water table for longer periods.

Lakes formed on the permeable limestone where groundwater controls lake levels contain water with approximately 400 p.p.m. T.D.S. The lake floor sediments that are exposed seasonally can maintain a grass cover indicating that salt accumulations are low. These low salinities are due to groundwater circulation. Holmes and Colville (1970) state that in this area the volume of the unconfined ground water in Victoria and South Australia "would be sufficient to irrigate 0.15×10^6 ha (0.37×10^6 acres)". There are confined aquifers below the lake area in which the water quality varies from 600 to 1300 p.p.m. T.D.S.

The lake bed materials would have been deposited from the time of lake formation to the present. Strand line dunes could be Pliocene to Pleistocene in age, and recent subaerial sand sheets and dunes have also been deposited in these areas. An outlier of the strand dunes occurs south of Bolac. Lava flows have formed a barrier between the old lakes of this dune field and the dune lakes to the west.

The total dissolved solids in the waters of these old lakes which have impermeable floors is greater than 15,000 p.p.m. In this locality there is a long history of lake replenishment from run-off water and evaporation, resulting in salt accumulation in the lake floor sediments and high water salinities.

2. Former river valley

Lakes with irregular shapes occupy an abandoned river valley north west of Horsham (Fig. 1). The flat floors of the lakes are up to three square miles in area and may be covered by five feet of water during the winter months.

Blackburn (1962b) has described the abandoned valley as a former course of the River Murray defeated by late earth movements which resulted in a northward tilt of the land mass. Blackburn stated that before the tilting, "The main river turned southerly near Horsham and joined an earlier Glenelg".

Pels (1966) and Bowler and Harford (1966) have described the history of the ancestral River Murray courses in the north. Blackburn's suggestion indicates that lakes in this abandoned course to the south would have been formed on sediments older than those of the northern ancestral system. The existence of this former river indicates wet climatic conditions. Climatic changes towards more arid conditions caused the cessation of river flow then lake formation on the river flood plain.

Lakes formed in the abandoned river environment are highly saline and in summer the water evaporates leaving a salt crust approximately one inch thick covering the black ooze of the lake floors.

3. Limestone

Tertiary limestone underlies an area centred around Bessiebell north east of Portland (Fig. 1). The land surface is strewn with lakes and ponds, which are rounded to irregular in shape and vary in size from one half acre to a few acres and in depth from a few inches to five feet. Recent soils, lake bed sediments and wind blown sands cover the Tertiary limestone.

This is a karst type landscape and the water has collected in solution-corroded depressions. The lake water levels are controlled by ground water so that most of the smaller ponds and lakes do not contain water in the summer months. Water quality varies from 100–300 p.p.m. T.D.S. and during summer the exposed lake beds support a grass cover. This area could contain a valuable water resource similar to that of the area mentioned earlier which straddles the Victorian-South Australia border.

The recent sediments of loose brown sand covering the plain indicate that the lakes were formed later than both the strand line dune lakes and the former river lakes. The sands are wind-blown and at present are subject to movement.

4. Lava field

Volcanic activity in the Western District began in the Upper Pliocene and continued intermittently until approximately 5,000 years ago. In some areas the lava underlies the strand line dunes and in other areas it flowed between the dunes. Lava flows disrupted the drainage systems and lakes and swamps were formed along river courses and at the edges of lava flows, e.g. at Willaura, and at Condah Swamp. Lakes were also formed between lava flows. Lake Corangamite, approximately 100 square miles in surface area (the largest lake in Victoria) was formed when lava flows blocked a former course of the Barwon River.

The lakes could have been formed from the beginning of the period of volcanic activity, and they have inundated a variety of sediments and rock types. The present lakes cover Tertiary marine sediments, Newer Basalt, and river sediments.

The larger lakes such as Lake Corangamite do not dry out seasonally, but the smaller lakes, swamps and ponds formed in the "stony rise" country are dependent on run-off water and ground water table fluctuations and do dry out seasonally.

Dunes (lunettes) occur around the eastern shorelines of the larger lakes, and have aided climatic history studies in lake areas. Currey (1964) stated that "The lunettes indicate previous high lake water levels and lunette successions in the Western District are evidence of a changing climate in the Recent Epoch". Other lakes have formed between the lunettes on the older lake sediments.

Lunette positions and wave cut terraces indicate that Lake Corangamite water level has fluctuated from R.L. 375 to R.L. 396 in the past (Fig. 2). The lake once covered an area of 700 square miles and a succession of sediments can be identified below the lake floor from echo-sounding charts (Fig. 3). Bowler, Ollier and Currey (unpublished) obtained core samples from the lake floor of Lake Corangamite with underwater boring equipment developed by the Geology Department, University of Melbourne. These cores revealed that a former land surface (Fig. 3, between b and d) existed on lake sediments below the floor.

A log of the bore completed by Bowler (unpublished) records Bore No. 2 (south of the Stony Ridge) as follows:

- 0–3" Brown grey lean clay (soft gel) (18,000 p.p.m. NaCl).
- 3"–4½" Dark grey lean clay with black carbonaceous staining.
- 4½"–9" Dark red brown lean clay (scattered fine sand).
- 9"–11¼" Dark brown lean clay (20,000 p.p.m. NaCl).
- 11¼"–1' Grey lean clay.
- 1'–1'2" Dark brown lean clay.
- 1'2"–1'3" Dark, red brown lean clay (gel-like) and *Coxiella* (24,700 p.p.m. NaCl).
- 1'3"–1'11" Dark grey lean clay (18,000 p.p.m. NaCl).
- 1'11"–1'11¼" Dark brown fine sand (9,900 p.p.m. NaCl).
- 1'11¼"–2'5¼" Light grey silty clay (12,000 p.p.m. NaCl).

The bore reveals that salt has accumulated at different rates, depending on the climatic conditions prevailing at the time of deposition.

Recent records of the Lake Corangamite water levels show a fluctuation from R.L. 391 in 1960 to R.L. 384 in 1970. Water salinities vary from 3,000 p.p.m. T.D.S. in Lake Bolac to 35,000 p.p.m. T.D.S. in Lake Corangamite.

Volcanic tuff is interbedded with the lake sediments at Lake Colongulac (Gill 1953) and east of Beac (Currey 1964) indicating that lake sedimentation and the later stages of vulcanicity were contemporaneous.

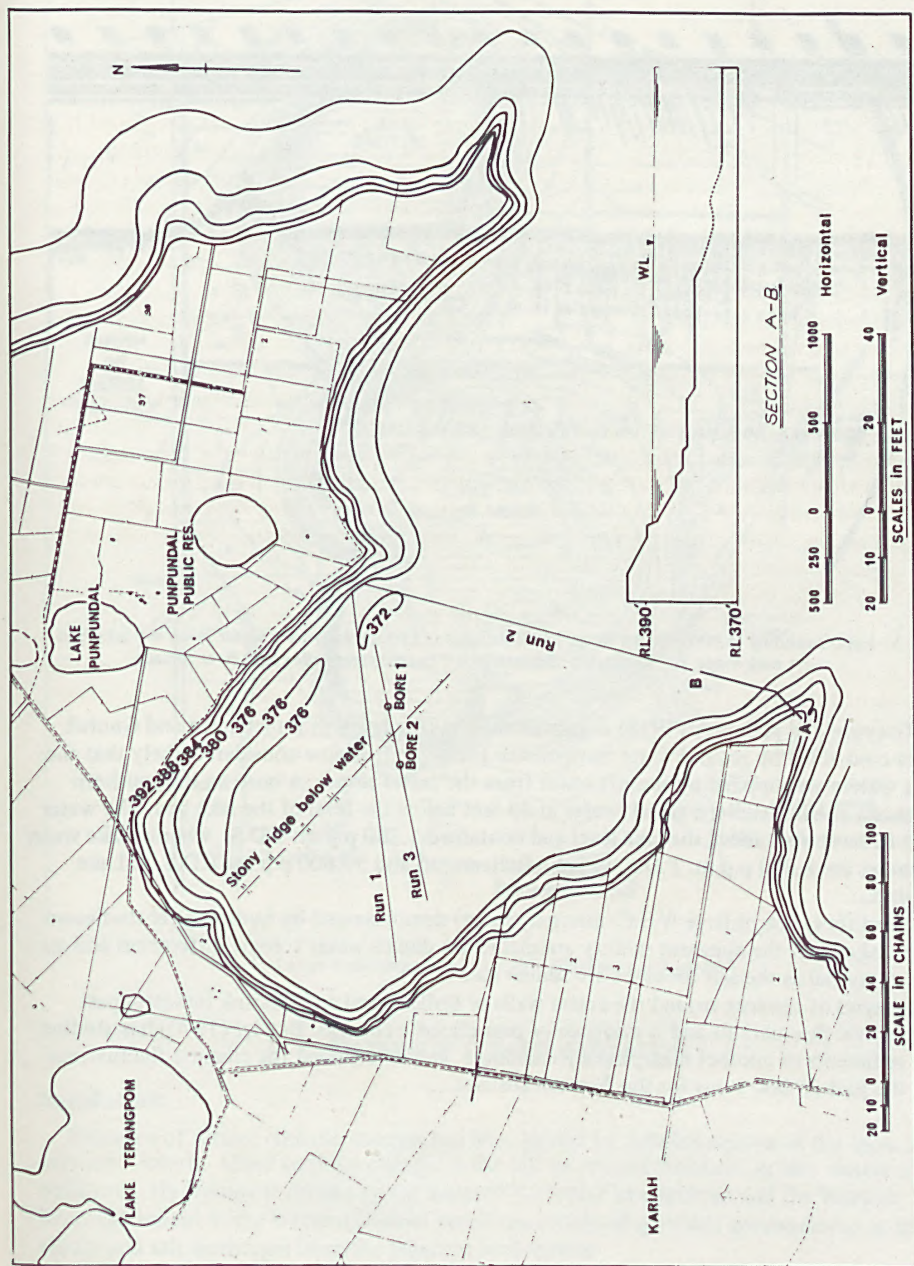


Fig. 2. Lake Corangamite (Leslie Manor). Echo sounding line (runs), with location of the underwater bores 1 and 2. Section showing lake terraces above and below water level.

5. Maar

Circular lakes up to 3 miles across occupy volcanic explosion craters (maars). Ollier and Joyce (1964) described and mapped the formation of the maars in the Western District. Examples of maar lakes are Lake Bullenmerri, 263 feet deep and Gnotuk, 45 feet deep (Fig. 4). The rock types exposed on the crater sides are Tertiary marine sediments capped by Newer Basalt.

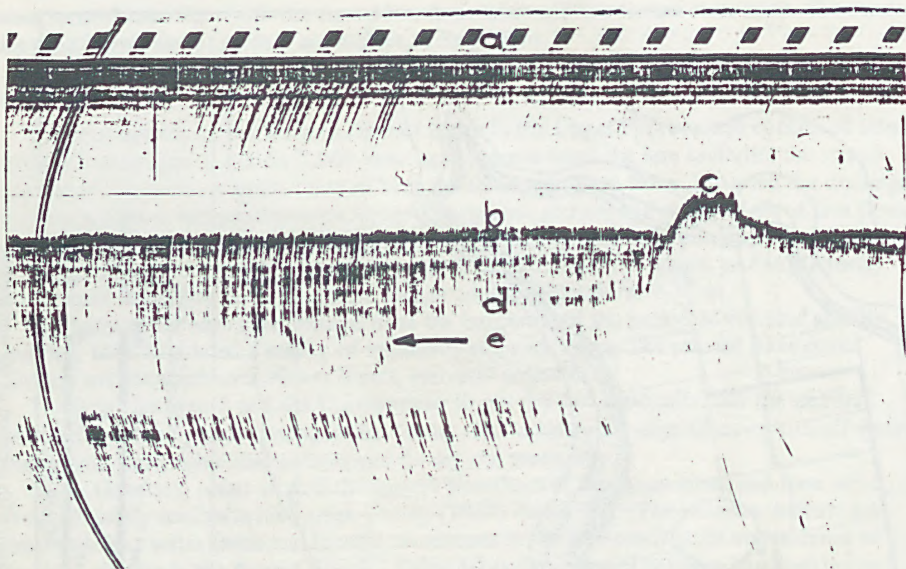


Fig. 3. Echo sounding chart between bores 1 and 2. Lake is 15 feet deep. a = water level b = lake bed c = rock ridge d = lacustrine sediments e = buried river valley and river terrace.

Grayson and Mahoney (1910) suggested that the lake levels at Bullenmerri and Gnotuk were controlled by ground water movements. However, it is now considered likely that the lake waters are supplied by run-off water from the crater slopes. A bore on the southern edge of Lake Bullenmerri struck water at 43 feet below the level of the lake bed. The water rose to seven feet above the lake level and contained 1,280 p.p.m. T.D.S., whereas lake water salinities are 8,800 p.p.m. T.D.S. in Lake Bullenmerri and 59,600 p.p.m. T.D.S. in Lake Gnotuk.

Sutcliffe (1966, S.R. & W.S.C. internal report) demonstrated by hydrological studies on these lakes that the apparent salinity anomalies are due to water volume differences and are not abnormal as the salt tonnages are similar (see later).

A series of terraces around the crater walls of Bullenmerri and Gnotuk indicates past water level fluctuations and is evidence of past climatic changes. Bowler (1970) has studied the sediments of another maar, Lake Keilambete, and determined the climatic fluctuations for the past 25,000 years for the Western District.

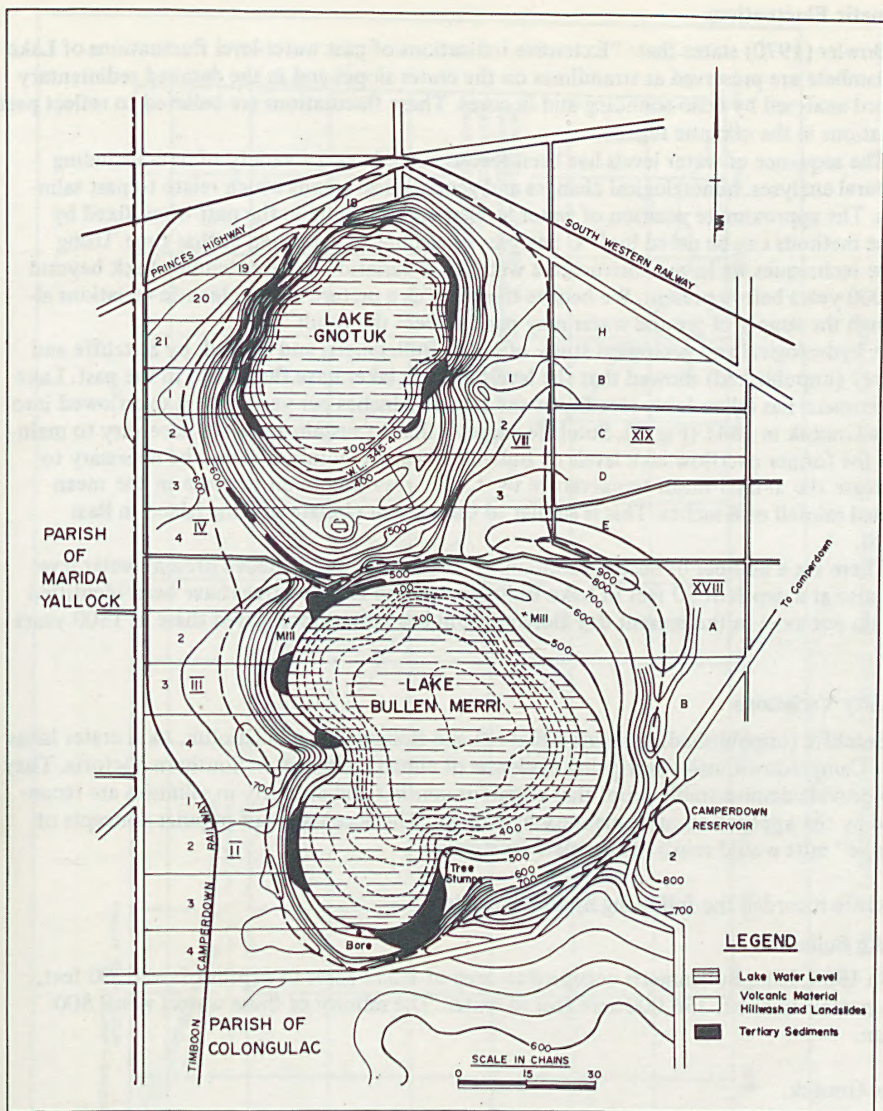


Fig. 4. Lakes Bullenmerri and Gnotuk. Contours and geology.

B. VARIATIONS OF CLIMATE AND SALINITY

Introduction

Evidence of former climatic changes has been gained by detailed studies of the lakes in western Victoria. Allied to these changes is the salt increment measured in lake waters and sediments. Hydrological studies on the western Victorian lake systems and the Wannon River catchment in the Western District reveal the relationship of salt accumulation in lake waters and salt discharges from the adjacent land masses.

Climatic Fluctuations

Bowler (1970) states that: "Extensive indications of past water-level fluctuations of Lake Keilambete are preserved as strandlines on the crater slopes and in the detailed sedimentary record analysed by echo-sounding and in cores. These fluctuations are believed to reflect past variations in the climatic regime.

The sequence of water levels has been reconstructed using a variety of data including textural analyses, mineralogical changes and geochemical trends which relate to past salinities. The approximate position of water level at any one time in the past when fixed by these methods can be dated by ^{14}C analyses of sediments deposited at that time. Using these techniques we have constructed a water level variation curve extending back beyond 25,000 years before present. We believe this gives us a picture of the climatic variations although the supply of ground water may partly affect the result".

A hydrological and geological study of Lakes Bullenmerri and Gnotuk by Sutcliffe and Currey (unpublished) showed that the levels of both lakes have fluctuated in the past. Lake Bullenmerri has fallen fairly steadily at the rate of 9 inches per year since it overflowed into Lake Gnotuk in 1841 (Fig. 5). Sutcliffe suggests that to sustain a rainfall necessary to maintain the former overflow lake levels of Bullenmerri and Gnotuk, it would be necessary to decrease the annual mean temperature by 1.5°F . resulting in an increase in the mean annual rainfall of 8 inches. This is similar to the present climate of King Island in Bass Strait.

There are a number of beaches containing tree stumps at and above present water level and also at a depth of 80 feet in Lake Bullenmerri. The exposed trees have been identified but do not exist in the present day flora and Gill has radiocarbon dated these at 1800 years B.P.

Salinity Variations

Sutcliffe (unpublished) has stated that: "Lake Bullenmerri and Gnotuk, twin crater lakes near Camperdown, offer intriguing evidence of climatic changes in Southern Victoria. They also provide demonstrable proof that apparent conflict and anomaly in salinities are reconciled by the application of elementary hydrology. The acceptance of popular concepts of "cyclic" salts would result in complete frustration".

Sutcliffe recorded the following hydrological data.

"Lake Bullenmerri:

In 1964, Lake Bullenmerri occupied an area of 1,232 acres to depths of over 200 feet, and contained about 156,000 acre feet of water. The salinity of these waters was 8,800 p.p.m.

Lake Gnotuk:

Lake Gnotuk now occupies some 520 acres at a comparatively shallow depth to about 45 feet and contains 24,000 acre feet of highly saline (59,600 p.p.m.) water.

The apparent anomaly of the twin lakes containing such contrasting salinities has given rise to many fascinating speculations and theories. A simple feasibility appraisal demonstrates that the salinities of both lakes are, on basic hydrologic characteristics, quite normal (See Table 1).

This is revealed by the salt tonnages of Lake Bullenmerri, 1,675,000, and Lake Gnotuk, 1,833,000. It is misleading to reconstruct salt histories by measuring lake water salinities without regard to water volume and other hydrological factors."

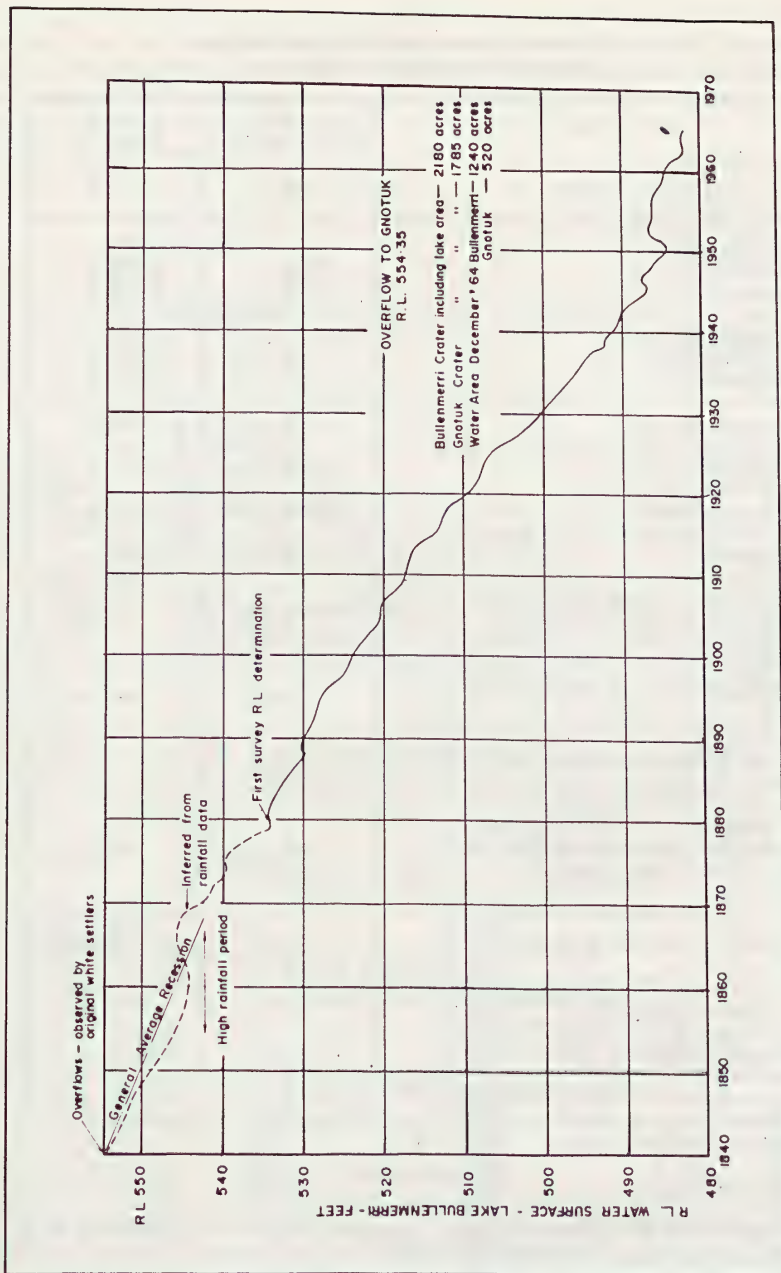


Fig. 5. Lake Bullenmerri. A record of lake level fall from 1840 to 1970.

Cyclic salt is salt falling on an area during rainfalls or deposited by winds. Although the term refers to salts from an oceanic origin it is sometimes used to refer to salts windborn from lakes. The cyclic salt contribution to Lake Bullenmerri and Lake Gnotuk from the crater slope run-off is less than 6% (Table 1).

TABLE 1
ILLUSTRATION OF SIMPLE RECONCILIATION OF
APPARENT SALINITY ANOMALY

	LAKE BULLENMERRI	LAKE GNOTUK
Gross area of crater	2,180 ac	1,785 ac
Area of water surface as observed 1881 as observed 1964	1,445 ac 1,235 ac	670 ac 520 ac
Crater slope drainage area at 1881 water level at 1964 water level	735 ac 945 ac	1,115 ac 1,265 ac
= Average area 80 years	840 ac	1,190 ac
Water contents 1964	156,000 ac. ft.	24,600 ac. ft.
Salinity of waters 1964	8,800 p.p.m.	59,600 p.p.m.
Salt content 1964	1,675,000 ton	1,833,000 ton
Average annual run-off to lakes from crater slopes (from rainfall-evaporation-recession balance over 80 years)	7.9 in.	5.3 in.
Estimated average annual salt increment from crater slopes	510 ton	550 ton
"Cyclic" salt deposited per annum on crater slopes at 60 lb/ac	25 ton	34 ton
Average salinity of run-off from crater slopes (from random tests, groundwater analyses and inferred from results from basaltic areas elsewhere)	800 p.p.m.	860 p.p.m.
Annual "cyclic" salt deposit on lake waters (60 lb/ac)	35 ton	20 ton
Gross salt increment per annum	545 ton	570 ton
Period of time to accumulate* present salt contents of lakes	3,100 yr	3,200 yr

* Not a valid period for the age of the lakes. Many other factors affect salt accumulation – deterioration, losses, wind action.

Wannon River Catchment:

A hydrological study of the Wannon River Catchment (Webster 1965) indicates the relationship between the geology and salt discharge in run-off water. It is evident that lake salinity studies are incomplete if the hydrology of the area is disregarded.

The Wannon River flows across the northern portion of the lake areas and is a tributary of the Glenelg River. Sutcliffe (unpublished) estimated the salt tonnages in the Wannon River from irregular salinity recordings and notes that these tonnages could be related to the geology in different parts of the catchment (Fig. 6). A summary of the hydrology and geology of the catchment shows these relationships (Table 2) The salinity increase in Jimmy's

Creek occurs because the catchment is in an area of decomposed granite. Similar high salinities come from the Little Tea Tree Creek catchment, which is also a deeply weathered land surface. These studies indicate that rivers derive most of their salt from the surrounding rocks, especially if the rocks are weathered. The contribution of cyclic salt to the salt load discharged from the catchment is approximately 8% of the total tonnage.

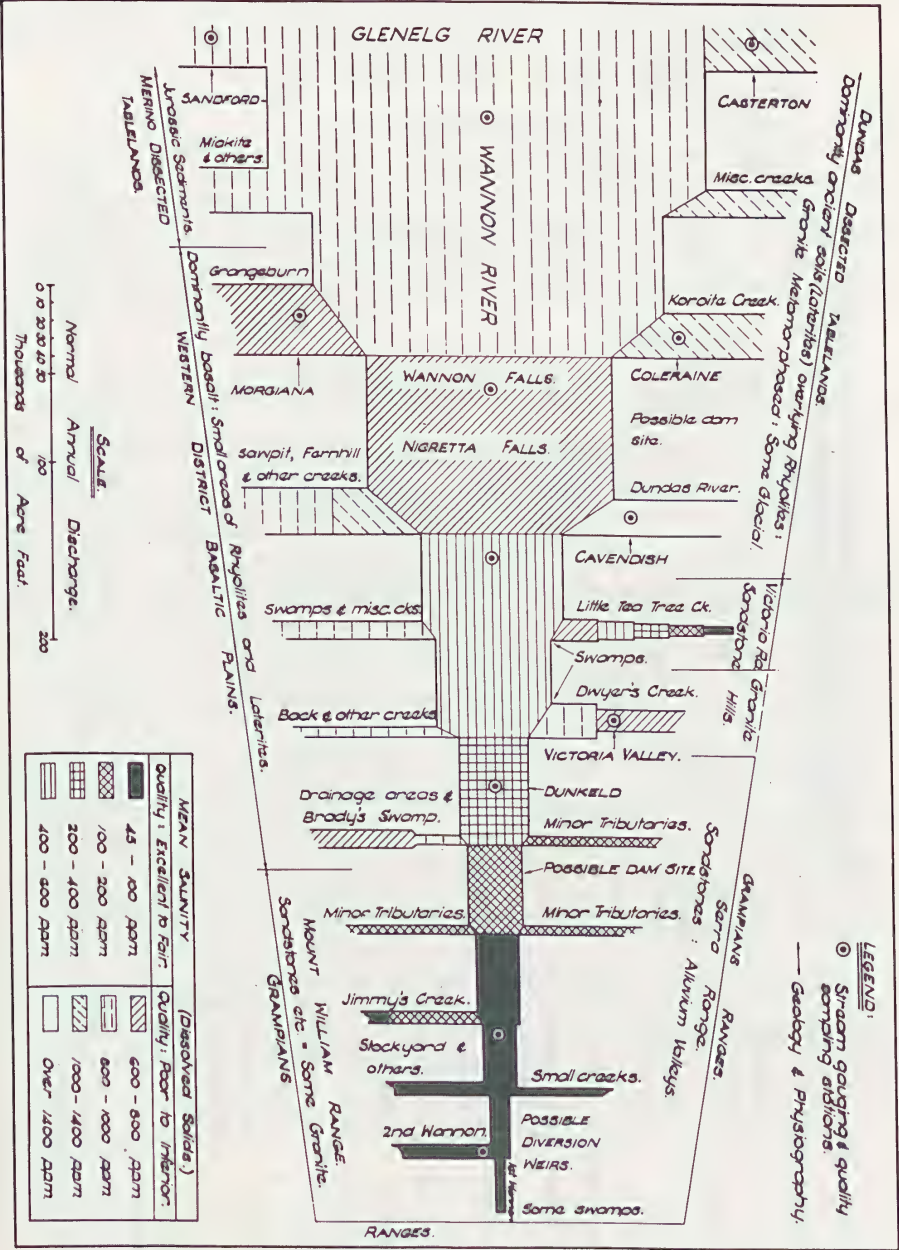


Fig. 6. Wannon River catchment. Water discharges and salinity diagram.

TABLE 2

INDEX OF "CYCLIC SALT" CONTRIBUTION TO THE SALINITY
OF WATERS OF THE WANNON RIVER AND TRIBUTARIES

Stream	General geology-soil type a) dominant b) secondary	Average annual catchment rainfall inches	Average annual run-off inches	Salinity of flows (p.p.m. T.D.S.)			Salts discharged in stream flows/ann. (lb/ac of catchment)	Cyclic salts (lb/ac of catchment)		Percentage contribution of cyclic salts to salinity of stream (approx. values)
				Mean	Max.	Min.		Annual deposit	Discharged to streams (60% factors assumed)	
Second Wannon	a) Sandstones	52.0	21.5	45	90	35	250	110	70	30%
Upper Wannon	a) Sandstones b) Alluvium	43.0	13.2	60	110	40	178	80	50	28%
Jimmys Creek	a) Sandstones b) Granodiorite	36.0	7.6	100	180	50	171	65	40	23%
Dwyers Creek	a) Granodiorites	27.4	2.2	750	2500	300	390	55	35	9%
Grangeburn	a) Basalt	26.6	2.6	790	3000	300	590	60	35	6%
Miakite Creek	a) Jurassic	26.2	2.5	970	3000	400	560	65	40	7%
Koroit Creek	a) Laterites b) Permian	26.5	3.4	1200	5000	450	925	55	35	4%
Dundas R.	a) Laterites b) Igneous	27.3	3.6	1500	6000	500	1225	50	30	2.5%
Combined Wannon R. Catchments		26.6	2.6*	850	3500	400	505	62	40	8%

* Subject to major losses.

Conclusions

Lakes in western Victoria can be grouped in one of five major geological environments. The ages of the lake areas are therefore different and climatic changes at various periods can be reconstructed by studying the land forms within each lake basin.

Lakes of western Victoria have been formed in many ways, but in all cases their salinities can be explained by conventional hydrological mechanisms. Salinity varies markedly among the various lakes. Only part of the salt content can be attributed to cyclic salt and the cyclic salt hypothesis cannot explain observed distribution of salt in a satisfactory way.

ACKNOWLEDGEMENTS

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I am also grateful for the helpful assistance given by Mr. T. Opie, State Rivers and Water Supply Commission, and Mr. C. D. Ollier, College of Advanced Studies, Canberra, and especially the information made available by Mr. A. J. Sutcliffe, State Rivers and Water Supply Commission.

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DESMIDS

(Abstract only)

by P. A. Tyler

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Despite their importance in the freshwater ecosystem, desmids are frequently neglected or imperfectly treated in limnological investigations. At least part of the reason for this neglect is the frustration caused by the chaotic state of desmid taxonomy. The obligate apomixis of many desmids has denied a genetic concept of species, and the taxonomic difficulties resulting from this are compounded by the proliferation of new taxa, based sometimes on a single specimen, and rarely on more than a single sample. Desmid taxonomy remains a labyrinth of comparative iconography.

TAXONOMY OF THE DESMID GENUS STAUSTRUM

(Abstract only)

by T. I. Chuah

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The desmid genus *Staurastrum* (Order Zygnematales, Family Desmidiaceae) constitutes a well-known but poorly defined taxonomic unit of freshwater phytoplankton, and specific identification is particularly difficult.

Plankton samples of *Staurastrum* from various lakes in Tasmania, mainland Australia and two overseas countries have been examined. Morphologically distinct populations have been found in samples from a single lake and between different lakes, although various degrees of seasonal morphological variation exists. Clonal cultures have also been used to study the maximum vegetative expression of a number of *Staurastrum* forms. The validity of morphological characters in delimiting *Staurastrum* species was discussed in the light of studies on morphological variations of *Staurastrum* in natural populations and in culture.

It is very probable that the genus contains fewer distinct entities than has been previously supposed. There is no doubt that long term observations on natural populations and the use of chemical characters are important in the elucidation of the taxonomy of this group. Hypotheses were put forward as to the probable affinities of the different *Staurastrum* group studied.

GROWTH AND CONTROL OF TWO SPECIES OF ANABAENA (CYANOPHYTA) IN A WATER SUPPLY RESERVOIR

(Abstract only)

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The paper presented dealt with the growth and control of a bloom of two species of *Anabaena* (*A. circinalis* Rabenh. and *A. solitaria* Kleb.) in the Prospect Reservoir of the M.W.S. & D.B., Sydney during 1969. Overseas, *Anabaena* spp. have been widely reported as causing water supply problems [see for example Jackson (1964) and Bellinger (1969)].

Prospect functions as a holding reservoir with two chlorinated inlets and three offtake points. It has a total capacity of $50.13 \times 10^6 \text{ m}^3$, with $8.87 \times 10^6 \text{ m}^3$ being available for supply; during 1969 the mean monthly discharge was $27.61 \times 10^6 \text{ m}^3$. At full supply level the surface area is 1338 ha, the greatest depth 24.1 m and the height above sea level 60.5 m.

Anabaena solitaria first appeared in Prospect samples on September 17, 1968 and maintained counts varying between 100 and 750 cells per ml. In May 1969 a second species, *A. circinalis* made an appearance and the two species reached a maximum count at the main offtake of 3500 cells per ml, with a ratio of *A. circinalis* to *A. solitaria* of approximately 7 to 1. The Board received complaints of taste and odour in the Prospect supply when *Anabaena* numbers exceeded 1000 cells per ml.

During the bloom, studies were made on the vertical and horizontal distribution of *Anabaena*. It was found that vertical distribution was affected by gas vacuole formation in the cells and by wind strength and direction, while horizontal distribution was influenced by wind. On July 22, 0–4.6 m tube samples at 10 sites varied between 663 and 4850 cells per ml with a mean of 3195, such variance resulting from strong winds.

Copper sulphate was dosed as an algicide by aerial application on July 24 to give a copper concentration of 0.15 mg/l in the 0–4.6 m zone. Most algal species in Prospect were susceptible to this dose with a five day decline in total cell count from 5910 to 2150. *Anabaena* spp. proved to be very susceptible with an 89% overall decline in numbers after 24 hr and a total disappearance by September 3. Amongst other forms the cryptomonads were completely eradicated and a rapid decline occurred in the filamentous diatom *Melosira*, while the blue-green *Cyanarcus* was copper resistant at the concentrations used and became dominant immediately after dosing. During the two month period after dosing, the reservoir was dominated by a series of transient opportunistic forms, namely *Ochromonas*, *Oscillatoria*, *Chlamydomonas*, *Dactylococcopsis*, *Dictyosphaerium*, *Rhizosolenia* and *Dinobryon*, before a return to a stable population dominated by the slower growing *Melosira*. None of these transient types showed any undesirable effect on water quality at the numbers encountered.

Amongst the zooplankton, copper sulphate had no apparent effect upon the copepods immediately after dosing. After three weeks a decline in numbers occurred, probably as a result of the non-availability of food. The impact of copper upon Cladocera was pronounced; *Bosmina meridionalis* was reduced by 86% of its pre-dose numbers within 5 days, and by 100% in 12 days. The rotifers were also drastically affected with a 98% decline in 5 days. Most zooplankton species had returned to normal levels by October 1969, probably due in the main to recruitment from the inflow waters.

Although other algal genera exhibited a similar pattern of development in 1970 to that of 1969, *Anabaena* had fortunately failed to re-appear by October 1970.

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ZINC LEVEL IN A NATURAL WATER (SNOBS CREEK) AND ITS ORIGIN

(Abstract only)

by J. C. F. Wharton

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The very small amount of information available on zinc levels in natural waters was noted together with the fact that these data refer usually to a single analysis for each water and do not throw any light on variation.

The results of 20 zinc analyses of an unpolluted water (Snobs Creek) in north-eastern Victoria were reported. Samples taken over a four-year period under varying conditions gave zinc values between 0.003 and 0.026 p.p.m.

The location of the Snobs Creek catchment was given together with a description of its geology, soils and vegetation. Methods of water sampling and analysis were described. Forestry practices and other activities in the catchment which could conceivably influence zinc pollution of the creek were noted and discussed. A typical chemical analysis of Snobs Creek water was presented and the similarity between this and the chemistry of major waters in north-eastern Victoria was noted.

Changes in the zinc present in creek water were shown to be related to rainfall in the catchment area, which increases both flow and zinc level. When the water level is stable or falling the zinc concentration is usually low.

Water in contact for some time with living branches and leaves taken from the principal types of vegetation growing in the catchment showed, on analysis, no gain in zinc. Analysis of sand, rock and organic material taken from the catchment suggested that the most important source of zinc in the creek water is the decomposing organic material of the forest litter layer.

The possible significance of the natural zinc levels in Snobs Creek was discussed in relation to trout production at the Snobs Creek Freshwater Fisheries Research Station which receives all of its water from the creek, and in relation to populations of wild fish living in the creek.

CHEMICAL CHARACTERISTICS OF TASMANIAN INLAND WATERS

(Abstract only)

by R. T. Buckney

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Some general features of Tasmanian waters were presented and discussed in the light of possible salt sources for waters, and the effect of rainfall. Most are dilute (T.D.S. 10–250 p.p.m. with a modal value of 25 p.p.m.), and have concentrations of major ions up to 0.5 meq/l, but extending to 1.9N for Mg in one salt lake.

The pH range recorded was 3.8–8.5, with most waters between 6 and 8. The low-pH waters are characteristic of the south-west of Tasmania; these are invariably highly coloured by humic material. There is a marked similarity in dominance ratios for these waters; a sea-water proportion of ions occurs throughout those areas where inert rocks are overlain by peat.

The Na/Cl ratio for all waters is close to that of seawater, except in the most concentrated. These facts seem to suggest that the major source of salts is the sea.

There are obvious geochemical effects associated with limestones, dolomites and other easily-weathered rocks, while dolerite which covers most of eastern Tasmania has an intermediate effect. There is thus a continuous dominance gradient from NaCl (seawater ratios) to CaHCO_3 . The geological differences also correspond with differences in vegetation, climate, topography and land use. The deviations from the modal trend may be explicable in terms of these.

ECOLOGY

ECOLOGICAL STUDIES ON SOME MICROBIOTA OF LAKES IN WESTERN VICTORIA

(Abstract only)

by S. U. Hussainy

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The ecology of some microbiota was studied in ten lakes covering a wide range of salinity (0.42–320 g/l) in western Victoria. The study began in November 1966 and continued until August 1969.

The lakes studied exhibited wide seasonal fluctuation in total dissolved solids, with concentrations highest in summer and lowest in winter. Lakes Pink, Weering and Cundare were dry in summer with a thick crust of salt at the bottom. There was no chemical stratification in any of the lakes.

Analyses of the lake waters for their ionic composition revealed a distinct ionic homogeneity. In all cases sodium dominated the cations, and chlorides dominated the anions. Except for Lakes Purrumbete, Elingamite and Keilambete, which contained more calcium and potassium, the order of cationic dominance was $\text{Na} > \text{Mg} > \text{K} > \text{Ca}$. Sulphate was usually present in relatively small quantities. The anionic dominance was $\text{Cl} > \text{HCO} > \text{SO}_4$. In Bullenmerri, however, sulphate was not detected on any occasion.

Wide fluctuations in water temperatures were recorded. Lakes Purrumbete, Bullenmerri and Gnotuk stratify during summer and are isothermal during winter and early spring. The annual heat budget was estimated for several lakes.

In freshwater lakes pH varied according to photosynthetic activity. Saline lakes, however, were well buffered, and photosynthetic activity had a very little effect on their pH. Marl deposition was seen on the littoral regions of Lakes Keilambete and Gnotuk.

The surface waters were supersaturated with dissolved oxygen both during summer and winter. During winter the oxygen stratification approached a near orthograde condition, and in summer, a clinograde condition with a depletion in the hypolimnion.

Seasonal variation of phosphate, nitrate and chlorophyll *a* was also studied during the investigation. These will be discussed elsewhere.

Standing crop and species composition of zooplankton during different months of the year were discussed. Mean depth does not seem to have any significant effect on standing crop. Total dissolved solids have a significant positive effect on zooplankton standing crop, and an inverse effect on species diversity.

Congeneric occurrences were recorded among Copepoda, Cladocera and Rotifera. The mechanism operating and permitting the coexistence of the allied species seems to be differences in body size.

Fluctuation in body size and egg production in calanoid Copepoda were investigated. Adult body size and egg number correlate positively with food but negatively with temperature and T.D.S. The effect seems to vary from species to species and for a given species from locality to locality. Depth of the locality also seems to inversely affect body size and egg number.

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SALT LAKE ECOSYSTEMS

by W. D. Williams

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A previous paper has dealt in general terms with energy transformations in salt lakes (Williams 1969). Some specific data on this subject now exist (Hussainy 1969; and unpublished) and much useful information on zooplankton species diversity with respect to salinity (but not on diversity spectra), primary production, chlorophyll *a* concentrations, and related matters of interest is now available for western Victorian salt lakes.

Nevertheless, a great deal remains to be done. There is still little information concerning the relative importance of periphyton and phytoplankton to total primary production in these lakes, many problems of biotic spatial heterogeneity have yet to be solved, and work on secondary production has hardly begun. Trophic-dynamic investigations are likely to continue for many years.

It is appropriate in the present circumstances to provide a general discussion in a second direction. The previous paper (Williams 1969) emphasized the simplicity of inland salt lakes as ecosystems for trophic-dynamic studies. However, the simplicity and, of equal importance, the *instability* of salt lakes suggests that they should also provide admirable objects for the sort of "macroscopic" approach to ecology that Margalef (1968), for example, says is necessary if we are ever to gain sufficient insight into ecosystem processes for a full appreciation of them. In this sense, inland salt lakes can almost be regarded as natural gnotobiotic systems. Already, "artificial" salt lake microcosms have been created (Nixon 1969), and there is no question that the gnotobiotic method potentially offers a powerful analytical tool for ecological studies. The difficulties of the logical extension to salt lakes in nature will surely not prove insuperable.

Of prime importance in this context is the instability conveyed to the environment by way of seasonal salinity fluctuations. Such environmental instability may be regarded as a form of exploitation and a means therefore of maintaining ecosystem immaturity (*sensu* Margalef 1968). Because such fluctuations vary in extent, it is possible to think of a series of salt lakes such as exists in western Victoria as a series of ecosystems spanning the spectrum of maturity, with a clear negative correlation between maturity and salinity.

What are the macroscopic parameters to be sought and studied? Amongst the most important are species diversity and diversity spectra, energy flow (or the ratio of production/biomass), total biomass, the ratio of gross production to community respiration, ecological efficiencies, pigment diversities, biochemical heterogeneity and others. Odum (1969) suggests many more. The determination of such parameters raises numerous difficulties in non-discrete and highly diversified and heterogeneous aquatic ecosystems; in salt lakes the determination seems a much more reasonable proposition. Work along these lines has hardly commenced yet, but if only to create interest, it is noted that in a series of five Victorian salt lakes in which Margalef's (1964) pigment diversity index (that is the ratio of optical density at a wavelength of 430 m μ to that at 665 m μ) was investigated, the trend was opposite to that predicted. The data were from samples collected in January 1970 and from which pigments in all phytoplankton greater than 5 μ size were extracted in acetone. (It should be emphasized that these are only preliminary results and the annual picture will be much more meaningful). But at all events, the results do indicate a unidirectional trend unlike those of others which appear inconclusive (e.g. Winner 1969).

Finally, stimulated by Margalef (1968), it is tempting to place briefly into a salt lake context his comments on evolution within the framework of ecosystem organization. Again, the salient point is that salt lakes are immature environments. As such, they possess a high proportion of fugitive and opportunistic species, and species with shallow survivorship curves and on which, consequently, natural selection will act most strongly in the early phases of life. The corollary is that evolution proceeds much more rapidly for such species.

Perhaps rapidity of evolution acts as counterbalance to the increased size of the gene pools of salt lake species — which necessarily must have good dispersal mechanisms. That is to say that the decreased rate of speciation of salt lake species to be expected because of the lack of well-defined geographical separation between populations is perhaps offset by an increased rate of speciation in the early phases of life of such populations. In this connection, a consideration of the evolution of *Parartemia* would be highly interesting. Why, for example, do six apparently “good” species exist in south-western Australia, yet only one in the south-east? At all events, the more general problem of the widespread faunal endemicity of Australian salt lakes also needs much more careful consideration than has yet been given it.

It should not, however, be thought that natural selection operates in an isolated fashion only upon the biota of salt lakes. There are cogent arguments for suggesting that it may operate also at the level of the ecosystem itself (here it is important to distinguish between ecological processes of succession and evolutionary processes of selection). Such arguments have been advanced by Dunbar (1960) who argues that selection will favour the creation of stability. The fact that salt lakes occur frequently in tropical and subtropical regions runs counter to Dunbar’s broad generalizations concerning stability and climate, but is beside the point here.

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STUDIES ON A SALT LAKE ECOSYSTEM

(Recorded here by title only)

by K. F. Walker

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PRIMARY PRODUCTION IN SALINE LAKES

(Abstract only)

by U. Theodore Hammer

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The saline lakes on the western volcanic plains of Victoria, Australia, are characterized by a paucity of plankton species. Continuous blooms of *Anabaena spiroides* in Red Rock Tarn and *Nodularia spumigena* in Lake Corangamite occurred with blooms of other species occasionally associated. Red Rock Tarn attained maximum primary production of 17.5 g C/m²/day in early January 1970 while Lakes Coragulac and Corangamite produced about 2 g C/m²/day during the summer. These lakes are undoubtedly eutrophic while Pink Lake producing only 20–63 mg C/m²/day is distinctly oligotrophic (probably secondarily) from the production point of view.

Primary production was significantly correlated with chlorophyll and dry weight in surface waters.

DAILY PRIMARY PRODUCTION ESTIMATES FROM SHORT-TERM INCUBATIONS

(Abstract only)

by U. T. Hammer,* K. F. Walker and W. D. Williams

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Primary production determined by use of light and dark bottle methods mostly refers to short-term (3–6 hr.) experiments, where conversion factors provide daily estimates. This is more expedient than summation over the entire day. A ¹⁴C experiment (20.i.1970) in Lake Corangamite, western Victoria, suggests factors of 2.6 and 2.8 applied to results from the second and third 3-hour daylight periods respectively. Similar experiments in Red Rock Tarn suggest factors of 3.4 (24.i.1970) or 3.7 (7.ii.1970) applied to the third 3-hour period. Data substantiate the notion that exposures > 6 hrs. lead to significant errors. In general, conversion factors relevant to each environmental situation must take into account seasonal ecological perturbations.

LAKES SORELL AND CRESCENT : A PHYCOLOGICAL ENIGMA

(Abstract only)

by D. M. H. Cheng

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From the close proximity of Lakes Sorell and Crescent, in an area of uniform climate geology and vegetation, one would expect the two lakes to have identical chemical and biological features. However, while they do resemble each other closely in their physical and chemical limnology the striking difference in their plankton populations is a phycological enigma. The latter fact placed an emphasis on a comparative approach.

The two lakes are situated on the central plateau of Tasmania, Sorell being over twice the size of Crescent. They are separated by a strip of land less than one and half kilometres wide, but are joined by a narrow channel. The flow is from Sorell into Crescent but the actual rate is regulated artificially by a sluice.

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The mean depths of Sorell and Crescent are respectively 2.4 and 1.8 metre. They were found to be isothermal and oxygen-saturated vertically throughout the year. They are thus considered as polymictic.

The hydrology of the lakes was observed to be a major factor affecting their seasonal chemistry and biology. The water budgets are relatively small, and the outflow of Sorell constituted an important source of water and nutrients, such as silica, for Crescent.

Both Sorell and Crescent are very soft waters, and of the chemical and physical parameters measured, only silica was found to be very different in the two lakes. Silica concentration in Sorell was in the order of 13 p.p.m. but only less than one p.p.m. in Crescent. All the major anions and cations were about 20% higher in Crescent. The differences in the general ionic contents of the two waters were attributed to differential loss of water from the water columns because Crescent is a shallower lake. The silica difference was however caused by heavy utilisation of these nutrients in Crescent by the very much denser algal crop which was dominated by diatoms.

There were on average 20–40 times more cells per unit volume of water in Crescent than in Sorell and the species compositions were also very different. There were more species in Crescent and many algae were found only in Sorell or Crescent, but not both. Seasonal fluctuations in algal densities and species composition in Crescent were of small magnitude. In contrast the seasonal cycles of the algae in Sorell were much more spectacular involving large and rapid changes. Some species appeared for a short time in Sorell during the period of investigation, but were not seen subsequently. It appears that Crescent is biologically a more mature lake, and is better buffered chemically.

Primary productivity measured by the ^{14}C method was always higher in Crescent, though the actual magnitude of this difference varied seasonally. Generally the differences were greater in summer and least in winter coinciding with the periods of highest and lowest rate of production in both lakes.

Short term experiments showed that phosphate stimulated production in water samples from both lakes and the effects of enrichment with other nutrients were small or not appreciable.

The reasons for this phycological enigma are still unknown, but differences in the morphometric parameters and age of the lakes are considered as possible factors.

PHYSIOLOGICAL ECOLOGY AND FISH STUDIES

PIGMENTATION OF SALT LAKE COPEPODS

(Abstract only)

by G. W. Brand

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In Victorian salt lakes the copepod *Calamoecia clitellata* Bayly exists as two morphological phenotypes whose occurrences seem to be related to salinity. The high salinity form is characteristically pigmented by substances identified as ketocarotenoids on the basis of their absorption properties, solubility in organic solvents, and specific tests. These were further resolved by column and thin-layer chromatography into a series of astaxanthin esters and free astaxanthin.

The presence of these typical crustacean pigments is of little interest *per se*. However, the same carotenoids were found, and in similar proportions, in the faintly grey-green low salinity variant. The effect of desiccation and denaturants on their coloration suggests that the pigments are bound to proteins.

While there is no general explanation for the widespread occurrence of carotenes and their derivatives in animals, their role, at least in the Crustacea, appears to be adaptive. In *C. clitellata* this may be unrelated to coloration. Experiments are in progress on this species to determine the factor(s) influencing the mode and extent of carotenoid deposition.

EFFECTS OF SUPERABUNDANT OXYGEN ON THERMAL TOLERANCE OF GOLDFISH

(Abstract only)

by A. H. Weatherley

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A hypothesis was proposed that respiratory/circulatory, and possibly oxygen transport, systems are importantly involved in thermal death of goldfish. Experiments showed that at two distinct levels of temperature acclimation superabundant oxygen could produce a definite improvement either in survival time at a fixed lethal temperature or in a lethal temperature reached as a result of gradual heating of the water containing the goldfish. Despite this positive effect of high oxygen, a clear cut failure of oxygen in excess of about 5 atmospheres partial pressure to produce further improvement in thermal tolerance, seems to imply the failure of some critical system directly affected by oxygen.

While they reveal nothing of the details of the mechanisms involved, the experiments certainly do not invalidate the proposed hypothesis, and they open a way to further investigations now under way.

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REPRODUCTIVE ADAPTATIONS IN SOME AUSTRALIAN FRESHWATER FISHES

(Abstract only)

by J. S. Lake

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The modes of reproduction of several fishes of the Murray-Darling river system in south-eastern Australia have been shown by Lake (1967a, 1967b) to be quite varied and adapted to the régime of floods and droughts.

In 1967 a study of the reproductive biology of some freshwater fishes of Queensland and northern Australia was commenced. The modes of reproduction of fishes in this area have hitherto been little understood. Indeed, most of the information was anecdotal and sometimes contradictory. However, the evidence collected to date shows that the fishes of much of this region have modes of reproduction adapted to deoxygenated and often very turbid water.

The following table gives some examples.

Mode of Reproduction	Fish Species	Family
Buccal Incubator	<i>Scleropages leichhardti</i> <i>Hexanematichthys leptaspis</i> <i>Glossamia aprion</i>	Osteoglossidae Ariidae Apogonidae
Body Brooder (eggs carried by male fish on a hook formed by the projection of the first dorsal fin ray)	<i>Kurtus gulliveri</i>	Kurtidae
Nest (in shallow water — parent fans eggs)	<i>Tandanus tandanus</i> (Probably most other plotosids — 10 additional species described from Australia)	Plotosidae
Egg scatterers (adhesive eggs on plants in shallow water. In some species adults also fan and protect eggs)	<i>Neoceratodus forsteri</i> <i>Nematocentrus maculata</i>) <i>Melanotaenia nigrans</i>) <i>Hypseleotris compressus</i>	Ceratodidae Melanotaenidae Gobiidae
Planktonic spawners (eggs float near surface, hatch within 48 hours)	<i>Plectroplites ambiguus</i>	Serranidae

A knowledge of the modes of reproduction of the fishes and the oxygen régime of the rivers of Australia have helped in an understanding of fish distribution. For example, the Fitzroy River system's watershed in Queensland joins the watershed of the Murray-Darling river system. *Plectroplites ambiguus* and *Tandanus tandanus* occur in both river systems. On the other hand *Maccullochella macquariensis* (Serranidae) and *Bidyanus bidyanus* (Theraponidae) occur in the Murray-Darling system but not in the Fitzroy system even though the habitat in this latter system appears not unsuitable. Water temperatures are well within these fishes' tolerance as are other factors. However, *M. macquariensis* lays eggs in hollow logs or under hard surfaces at depths greater than 1 metre, usually where the water is flowing. The eggs of *B. bidyanus* are more dense although similar to those of *P. ambiguus* and will sink more readily. *M. macquariensis* and *B. bidyanus* would thus be unlikely to reproduce in rivers such as the Fitzroy since oxygen is often lacking at quite shallow depths, sometimes at less than 1 metre.

Financial support from the Research Grant of the University of Sydney and the Australian Research Grants Committee is gratefully acknowledged. To Mr. S. H. Midgley of Nambour, Queensland, I offer my sincere thanks for his assistance in the field and for his valuable suggestions.

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REPOPULATION OF EXPERIMENTALLY DECIMATED
SECTIONS OF STREAMS BY LONGEAR SUNFISH
LEPOMIS MEGALOTIS MEGALOTIS (RAFINESQUE),
AND THE SIGNIFICANCE OF AGE STRUCTURE,
HOME RANGE, AND MOVEMENTS

(Abstract only)

by T. M. Berra

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Repopulation of decimated stream segments in Louisiana by longear sunfish was studied. Six study areas on four streams were decimated by electro-fishing. At three areas, fish upstream and downstream from the decimated sections were marked and released. Repopulation on a total weight basis by *Lepomis m. megalotis* to a level as great or greater than the decimation sample occurred at four of the six areas within one year. The repopulation level varied from 0.3 to 3.5 times the decimation level. Repopulation occurred in the interim between March and late summer and was accomplished by fish over two years old which were probably strays from other areas although this needs further study.

The mark-recapture data indicate that longear sunfish probably deserted their home ranges during the winter and that smaller fish occupied shallow headwaters during the cold months. Most of the marked fish (79%) were not recaptured indicating that they failed to return after their winter movements or died. Of the 72 recaptured fish 71% were within their marking sections which averaged 128 feet indicating that there is a stable element in the population as well as a mobile element. No difference in the number of fish straying upstream or downstream was observed nor was there a difference in the size of the fish that remained in the marking section or that strayed out of it.

ASPECTS OF THE PHYSIOLOGY AND
ECOLOGY OF *HALONISCUS SEARLEI*
(CRUSTACEA : ISOPODA : ONISCOIDEA)

(Recorded here by title only)

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Anyone requiring further information on this paper should consult the following references:

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Editorial Note

THE FOLLOWING PAPERS WERE NOT READ AT THE NINTH ANNUAL CONGRESS BUT REPRESENT ORIGINAL CONTRIBUTIONS SUBMITTED FOR PUBLICATION FOR THE FIRST TIME IN THE BULLETIN.

A NOTE ON THE ZOOPLANKTON OF THE MOUNT KOSCIUSKO REGION

by Ian A. E. Bayly

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INTRODUCTION

The eighth annual congress of the Australian Society for Limnology at Jindabyne in February 1969 provided an opportunity for collecting from the cirque lakes near Mt. Kosciusko (the highest lakes in Australia) and other high altitude localities.

On the day preceding the conference proper (22.ii.1969), several members of the society, including myself, under the guidance of Dr. V.H. Jolly, converged on Lake Jindabyne (an artificial impoundment of the Snowy Mountains Scheme) in a combined effort to study its plankton and benthos. The intention was that the results of the study of all the material collected would be published in the A.S.L. Bulletin in a single article under multiple authorship. Since it now appears that the original objective will not be realized, it is worthwhile publishing the results of the plankton work* and thermometry separately.

RESULTS OF ZOOPLANKTON SAMPLING

At each locality the species are listed in order of descending abundance.

- (1) Lake Cootapatamba (altitude 2070 m)
Daphnia carinata King *B. montana* Bayly
Boeckella pseudochelae Searle *Acanthocyclops* sp.
- (2) Hotel Kosciusko Reservoir (altitude ca. 1650 m)
Bosmina (? *meridionalis* Sars) *Macrocyclus* sp.
Boeckella triarticulata (Thomson)
- (3) Small pond adjacent to Rawson's stream, between Albina Saddle and Seaman's Hut
(altitude ca. 1900 m)
Boeckella montana *Macrocyclus* sp.
- (4) Small (?kettle) lake just above Lake Albina (altitude 1925 m)
Boeckella montana *Daphnia carinata*
- (5) Shallow pool on peaty bog between (4) and (6) (altitude 1922 m)
Boeckella montana *B. pseudochelae*
- (6) Lake Albina (altitude 1920 m)
Boeckella montana *Macrocyclus* sp.
Daphnia carinata

* See also the following article by I. J. Powling.

- (7) Blue Lake (altitude 1890 m)
Asplanchna sp.
Attheyella (*Delachauxiella*) sp. (these were presumably caught when the net touched the bottom)
Alona sp. *Camptocercus* sp.
Eucyclops sp. *Chydorus* sp.
 Many rotifers were present including *Keratella*, *Polyarthra* and *Monommata*
- (8) Small shallow pool about 10 m² cut off from Hedley's Tarn by about 20 m (altitude 1860 m)
Boeckella montana
Macrothrix sp.
 It may be noted that Hedley's Tarn itself was at the time of collecting an essentially lotic habitat lacking plankton.
- (9) Shallow swampy pool between Eucumbene and Bald Hill (altitude ca. 1525 m)
Limnadia sp. *Boeckella pseudochelae*
Limnetis sp. *B. major* Searle
- (10) Lake Tooma (artificial) (altitude 1230 m)
Boeckella montana *Asplanchna* sp.
Diaphanosoma sp.
- (11) Lake Jindabyne (altitude ca. 915 m)
 Plankton collections were made well offshore by boat at three different stations as follows : (i) about 0.5 km from the dam, (ii) in the bay into which flow the Crackenback and Snowy rivers and (iii) a station between (i) and (iii). All collections were essentially similar and may be reported thus:
- | | | |
|---|---|--------------|
| <i>Boeckella triatriculata</i> |) | Co-dominant |
| <i>Daphnia carinata</i> | | |
| <i>Ceriodaphnia</i> sp. | | Sub-dominant |
| <i>Mesocyclops</i> (<i>Thermocyclops</i>) sp. Common | | |
| <i>Microcyclops australis</i> (Sars) Relatively scarce but some specimens present in all three collections. | | |
- In addition, a few water mites were present.

PHYSICAL MEASUREMENTS IN LAKE JINDABYNE

A thermistor thermometer was used to measure temperature at a series of depths at three stations. The mean temperature-depth curve is shown in Figure 1. Secchi disk readings were also taken at three stations, the mean value being 4.3 m.

DISCUSSION

The records of *Boeckella montana* are of interest in considerably extending the previously known distribution. The species was originally described (Bayly 1964) from two high-altitude localities near Uralla in north-eastern New South Wales. Since then, Timms (1970b) has recorded the species from three additional localities in this region, all of them lying in the altitude range 1024–1372 m. These and the present records consolidate the hypothesis that *B. montana* is restricted to high altitude localities on the Australian mainland, but it is now clear that it is not restricted to the north-east of New South Wales as previously suggested.

The *B. montana*-*B. pseudochelae* association occurred twice but was not found by Timms (1970b), the latter species apparently being absent from north-eastern New South Wales. It is noteworthy (Bayly 1964:181) that these two calanoids differ markedly in size, *B. pseudochelae* being by far the larger. Measurement of 10 species of each sex of both species from locality (5) above gave the following mean lengths (exclusive of furcal setae): *B. pseudochelae* ♀ 1.68 mm, ♂ 1.42 mm; *B. montana* ♀ 1.16 mm, ♂ 0.96 mm. These size differences, although marked, are much less than those that would have existed in the *B. montana*-*B. major* coexistence recorded by Timms (1970b).

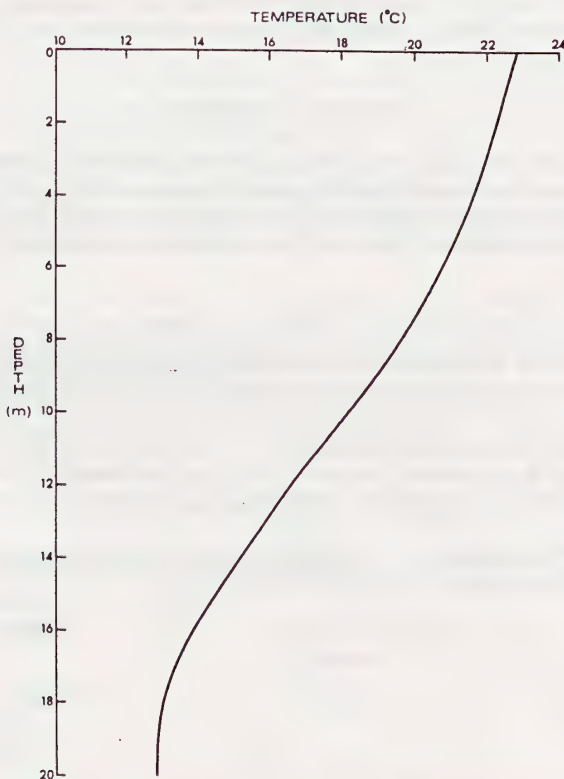


Fig. 1. Temperature—depth graph for Lake Jindabyne, February 22, 1969.

Despite earlier reservations about the distinctness of *B. montana* (Bayly 1964:230) it is now considered quite different from *B. delicata* Percival. This distinctness is reinforced by the discovery of the occurrence of these two species in the same general area; there is no difficulty in distinguishing the Mount Kosciusko form from that in Lake Eucumbene (Bayly 1964:223).

B. pseudochelae was found co-existing with *B. major* at locality (9) but this has not previously been reported for N.S.W.. It has, however, been previously found in Tasmania (Bayly 1967:101).

It is interesting that *Microcyclops australis* is capable of living a truly limnetic existence in a water body as large as Lake Jindabyne. It has previously been recorded only from small lentic habitats. The species of *Mesocyclops* present in this lake is very small and is definitely not the ubiquitous *M. leuckarti* (Claus).

It is noteworthy that the specimens of *Daphnia carinata* from locality 1, but not 4, differed from the typical Australian form in that the postero-dorsal carapace spines were almost completely lacking. Dr. V.H. Jolly (pers. comm.) has found the same condition in specimens from the Great Lake in Tasmania and also from Macquarie Island. This particular morphological condition may well be a response to very low temperatures. Specimens from locality 4 had a considerably reduced spine.

Although there is a 10 degree difference between top and bottom temperatures in Lake Jindabyne, the temperature-depth curve is not of the usual type for a thermally stratified lake (cf. Timms 1970a, fig. 1, Somerset Dam). The metalimnion limits are approximately 8–17 m but the thermocline is asymmetrically placed within this at about 10 m.

ACKNOWLEDGEMENTS

I wish to thank Mrs. Maureen Lewis (University of Auckland) for identifying the harpacticoid copepod *Attheyella* (*Delachauxiella*) and also Dr. V.H. Jolly (University of Auckland) for verifying my identification of *Daphnia carinata* from Lake Cootapatamba. Thanks are also due to Messrs. G. Brand and G.H. Arnott who assisted with the work on Lake Jindabyne.

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A NOTE ON THE PHYTOPLANKTON OF THE MOUNT KOSCIUSKO REGION

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INTRODUCTION

The introduction to the previous paper (Bayly 1970) applies also to a series of collections of phytoplankton from the same localities in February 1969. As a result of these collections, and the discovery of an interesting species of *Micrasterias* in the Lake Cootapatamba sample, a further visit was made the following February by Dr. P.A. Tyler of the University of Tasmania, Dr. Susan McGill of the Fisheries and Wildlife Department, Victoria, and the author. On this second occasion several new localities were sampled in the region of Lake Albina. The system of locality numbering employed below corresponds with that used in the previous paper, but the extra localities sampled in 1970 are distinguished by the addition of letters

The results are those of net collections only; no quantitative assessment was made. The net used on each occasion was of silk bolting cloth of 60 micron mesh size. In all cases the species are listed in order of abundance from greatest to least. From the taxonomic viewpoint the main emphasis is on desmids.

Unless otherwise stated, all hydrogen-ion concentration values and electrical conductivities quoted below were measured in S.R. & W.S.C. laboratories.

RESULTS OF PHYTOPLANKTON SAMPLING

(1) Lake Cootapatamba — pH 5.7, K_{18} 5 $\mu\text{mho cm}^{-1}$

1969	1970
<i>Surirella robusta</i>	<i>Surirella robusta</i>
<i>Stigonema</i>	<i>Stigonema</i>
<i>Micrasterias jenneri</i> *	No desmids
<i>Staurastum</i> *	
<i>Staurodesmus</i> *	
<i>Euastrum</i> *	
<i>Cosmarium</i> *	
<i>Pleurotaenium</i> *	
<i>Cyclotella</i>	
<i>Synechococcus</i>	
<i>Mougeotia</i>	
<i>Zygnema</i>	
<i>Ulothrix</i>	

Stigonema is a blue-green filament with more than one series of cells within a gelatinous sheath. Heterocysts are present. This was the predominant algal species in both years with the exception of the diatom *Surirella*. *Stigonema ocellatum* (Dillw.) according to Prescott (1954) is invariably found in desmid habitats but in this case identification has not been taken to species level.

* Desmid genera and species.

- (2) Hotel Kosciusko Reservoir — pH 6.0, K_{18} 16 $\mu\text{mho cm}^{-1}$, 1969 only

Tabellaria

Fragillaria

Closterium 4 species*

Staurodesmus 2 species*

Cosmarium 3 species*

Euastrum (small)*

*Staurostrum sexangulare**

*Micrasterias laticeps**

*St. tohopokaligense**

- (3) Not sampled for phytoplankton either year.

- (4) Small (?kettle) lake just above Lake Albina. No phytoplankton found either year.

- (5) Shallow pool on peaty bog between (4) and (6).

1969

1970

Surirella

Eremosphaera

Ulothrix

Chroococcus

*Staurostrum**

Stigonema

*Staurodesmus**

Oedogonium

*Pleurotaenium**

*Euastrum**

*Cosmarium**

*Micrasterias jenneri**

Cosmarium (small)*

*Pleurotaenium**

- (5A) Grassy pond near Lake Albina

Eremosphaera — the predominant species present in both years, imparting a green colour to the pond.

*Staurodesmus**

Stigonema

*Micrasterias jenneri**

Botryococcus

*Micrasterias truncata** (1969 only)

*Pleurotaenium** (1969 only)

- (6) Lake Albina — pH 5.7, K_{18} 6 $\mu\text{mho cm}^{-1}$

1969

1970

Surirella

Surirella

Dinobryon divergens

Dinobryon divergens

Eudorina

Closterium kuetzingii

- (6A) Tarn beyond Lake Albina on western side — 1970 only

*Staurostrum**

Spirogyra

*Pleurotaenium**

Oedogonium

*Staurodesmus**

Bulbochaete

*Micrasterias jenneri**

Botryococcus

*Closterium**

Chroococcus

Euastrum (small)*

Cosmarium (small)*

* Desmid genera and species.

(6B) Club Lake — pH 6.2, K_{18} 5.3 $\mu\text{mho cm}^{-1}$ (from Williams, Walker and Brand (1970))

<i>Cosmarium</i> *	) both small	<i>Surirella</i>
<i>Closterium</i> *		<i>Fragillaria</i>
<i>Dinobryon divergens</i>		

(7) Blue Lake — pH 6.0, K_{18} 6 $\mu\text{mho cm}^{-1}$

No phytoplankton either year, apart from a small amount of the green filament *Ulothrix*.

(8) Not sampled.

(8A) Hedleys Tarn — 1969 only

<i>Staurastrum</i> *	<i>Zygnema</i>
<i>Stauroidesmus</i> *	<i>Mougeotia</i>
<i>Arthodesmus</i> *	<i>Rhizoclonium</i>
	<i>Oscillatoria</i>

(9) Not sampled

(10) Lake Tooma (artificial) — 1969 only

<i>Staurastrum</i> *	<i>Cosmarium</i> *
<i>Stauroidesmus</i> *	<i>Xanthidium</i> *
<i>Hyalotheca</i> *	<i>Pleurotaenium</i> *
<i>Closterium</i> *	

(11) Lake Jindabyne (artificial) — 1969 only

<i>Sphaerocystis</i>	<i>Volvox</i>
<i>Micrasterias hardyi</i> *	<i>Botryococcus</i>
<i>Staurastrum pingue</i> *	

DISCUSSION

The glacial lakes of the Kosciusko plateau all have very dilute acidic waters with less than 0.2 p.p.m. of both calcium and magnesium (Williams *et al.* 1970). Such waters are said (Hutchinson 1967) to provide very favourable habitats for desmids, which fact is borne out by the large number of species of this group present in some of the Kosciusko lakes.

Most localities contained the same desmid genera on each occasion, with the exception of Lake Cootapatamba. This cannot be explained by a sampling error as 1969 was the year when the conditions were least favourable for a net sample. In 1970 many samples were collected from all parts of the lake.

Further details of the taxonomy of the *Micrasterias* species of the area will be found in Tyler's (1970) paper.

* Desmid genera and species.

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ON THE PROPOSED INTRODUCTION OF *LATES NILOTICUS* (L.) TO AUSTRALIA

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It has been suggested recently that the Nile Perch, *Lates niloticus* (L.), be introduced to Australia and New Guinea; the suggestion was made initially by Midgley (1968, 1969) who, on the basis of a three-month investigation of the species in Uganda, Africa, recommended (1969:5): "that *Lates niloticus* be introduced to suitable waters in Northern [sic] Australia and the Territory of Papua and New Guinea."

The main purpose of this note is to record further viewpoints on this subject as well as summarize some recently published information on the ecology of *L. niloticus* that could otherwise escape immediate attention in Australia. It is motivated by the fact that consideration is being given to the proposal to introduce *L. niloticus* to Australia by the Committee for the Importation of Food and Sport Fish (an advisory committee of the Australian Fisheries Council).

It should firstly be emphasized that little precise information is available concerning the effects of *L. niloticus* introductions in Africa (Gee 1969; Greenwood, personal communication, 3.vii.1970), where it is endemic in two lakes, Albert and Rudolf, and in rivers from West Africa to the Nile (Gee 1969; Lowe-McConnell, personal communication, 16.vii.1970). However, Gee's paper (published after Midgley's proposal) provides some useful and pertinent information on the biology of *L. niloticus* in two localities to which it has been introduced (Lake Victoria and Kyoga). This can be summarized as follows:

1. *L. niloticus* can easily and successfully be introduced into a wide variety of waters, both natural and artificial.*
2. It exhibits, for a tropical species, a wide range of tolerance for non-endemic environments.*
3. It does not feed specifically on any one species or group of fish but is catholic in diet. Fish, insects, crustaceans and molluscs are recorded as stomach contents (table II, p. 253) (Hamblyn (1966) notes that invertebrates form a significant part of the diet of *Lates* specimens < 60 cm long).
4. Large *Lates* generally consume a larger number of small prey rather than fewer large ones.
5. It is a voracious predator.

The above represents, it is believed, fairly cogent evidence that certain dangers are attached to the introduction of *L. niloticus* to Australia with respect to the endemic freshwater fauna. Until further work is available, indicating more precisely the possible effects of the introduction of *L. niloticus* on the fauna of inland waters of northern Australia, it is urged that no introduction of this predatory and euryoecious species be made.

This suggestion is supported by various fisheries biologists *who have worked on African fish*. Dr. P.H. Greenwood, Head, Fish Section, British Museum (Natural History), writes (personal communication, 3.vii.1970):

"I am definitely opposed to the Nile Perch being introduced into Australia . . . there is so little information on *Lates niloticus* that it is impossible to forecast the effects on your local fauna or even to tell if . . . [it] . . . will stand any change of establishment . . . I felt that it is a gamble and a very premature action in the light of the relative paucity of information about the species in its natural and introduced habitats in Africa, and the paucity of information about the basic hydrobiology of the streams and rivers into which it is proposed that it shall be introduced.

* Gee notes as a corollary that it is probable that the species will in future be used even more for stocking suitable environments in various parts of the world.

"Also I feel that there is no convincing argument . . . as to why another exotic element should be introduced into your own very interesting and still poorly studied fresh-water fauna."

Dr. G.A. Prowse, Director, Tropical Fish Culture Research Institute, Malaysia, writes (personal communication, 26.vi.1970):

"Summing up, I would say that the introduction of *Lates niloticus* could lead to the wiping out of a large number of your native fauna."

Dr. R.H. Lowe-McConnell, Streatwick, U.K., writes (personal communication, 1.vii.1970)

"I would be very much against such an introduction. I do not feel that we know nearly enough about either (a) the biology of *Lates niloticus*, or (b) the fauna of the waters into which they would go, to risk the introduction of such a highly predatory fish."

In addition, Dr. Robert R. Miller, Curator of Fishes at The University of Michigan, who spent eight months collecting in the Northern Territory in 1948 (Arnhem Land Expedition), writes (personal communication, 3.viii.1970):

"There is every likelihood that the introduction of the large and versatile, predatory *Lates niloticus* would wipe out significant elements of the native fish fauna of northern Australia, much of which has not received the detailed scientific study that it deserves. This region supports a limited but very interesting number of fishes, essentially derived from marine types, which, once decimated, would leave little for *Lates niloticus* to eat. Moreover, a species of *Lates* (*Lates calcarifer*) already inhabits the coast and inland waters of northern Australia and the effects of the interaction between two species of this genus are unpredictable."

Fryer (1960) argued cogently against the introduction of *L. niloticus* into Lake Victoria, and his views remain the same on its proposed introduction to Australia; he writes (personal communication, 27.vii.1970):

"To transfer this fish to Australia would, in my opinion, be a foolish and dangerous thing to do, and I hope that wiser counsels will prevail."

Unfortunately, from the scientific viewpoint, Fryer's arguments were disregarded in Africa with the result that at least part of the highly endemic and biologically interesting fish fauna of this lake (*Haplochromis* with 117 species) is now subject to very heavy predation (Gee 1969, table II). Explicit misgivings on the possibilities presented by this situation have been expressed by Dr. J. Rzoska, Scientific Coordinator, International Biological Programme (Section PF) (personal communication, 19.xii.1969). Let us hope that a greater degree of sophistication concerning *L. niloticus* introductions prevails in Australia where, in any event, there does not exist the same pressure to increase the catch of inland fish for human consumption as exists in Africa. The commercial fish catch from certain African lakes (e.g. Lake Kyoga, Gee 1969, table V) has indeed increased since the introduction of *L. niloticus*, but the need to supplement African diets is no valid argument to support the introduction of *L. niloticus* to Australia.

It has been suggested that, if introduced, *L. niloticus* would merely occupy the niche of a similar native species, *L. calcarifer*, now decreasing in abundance because of man's alteration of the aquatic environment (impedance to spawning activities). This could be true, but the close correspondence of trophic niches of *L. niloticus* and *L. calcarifer* is surely questionable when such profound differences as are evident in reproductive biology occur (the former breeds in fresh water, the latter in estuaries). Moreover, it is not possible to predict accurately the ecological behaviour of *L. niloticus* when transferred from one environment to another, as stressed by Fryer (1960), and, indeed, as indicated by the intra-African transferences (Gee 1969).

It has also been suggested (Weatherley and Lake 1967) that introduced fish in Australia interfere less with indigenous fish than has been claimed. However, several of the premises on which this suggestion is based are subject to considerable debate amongst ecologists, and it has also been said that with reference to fish the phenomenon of interference (interaction, competition, predation) has been most clearly demonstrated in connection with introductions of exotic species (Nilsson 1967).

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VARIATIONS IN THE WATER CHEMISTRY OF FOUR SMALL LENTIC LOCALITIES IN THE HUNTER VALLEY, NEW SOUTH WALES, AUSTRALIA

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Inland waters may exhibit wide seasonal fluctuations in salinity. In Australia, Bayly and Williams (1966) noted that athalassic saline waters may vary within the range 3,300–322,000 p.p.m., the mean percentage fluctuation for 16 lakes being 502%. For fresh waters (i.e. < 3,000 p.p.m. salinity, after Williams (1964)), the degree of fluctuation is much less (Table 1). The localities listed in Table 1 do not include farm dams and other small bodies of fresh water – a common type of inland water in Australia. Weatherley (1967 p. 13) has predicted wide changes in chemical composition for these.

TABLE 1
SEASONAL PERCENTAGE FLUCTUATIONS IN SALINITY
IN VARIOUS AUSTRALIAN FRESHWATERS*

Localities	Range of percentage fluctuations	Mean percentage fluctuation for group	Source of data
Four closed lakes, Mt. Gambier, South Australia.	17–94	53	Bayly & Williams 1966
Six reservoirs, Sydney, New South Wales	19–97	56	Beer, in Williams 1967
Four reservoirs, Spencer Gulf, South Australia	105–140	125	South Australian Engineering & Water Supply Dept. in Williams 1967
University pond, Brisbane, Queensland	—	130	Timms 1967

* Calculated by dividing the difference between the maximum and minimum values by the minimum, and then expressing the result as a percentage.

The purpose of this note is to show (a) that small freshwater bodies may fluctuate widely in salinity, (b) that the extent of this fluctuation is related to the rate of water renewal, and (c) that, even in fresh waters, inorganic ions may concentrate at different rates as the water level falls.

Four lentic localities in the Maitland-Cessnock area, 90 km north of Sydney, were studied. This region has a mean annual precipitation of 70 cm, which is normally evenly distributed throughout the year but which is occasionally so erratic as to cause floods and droughts (Tweedie 1963). Mean annual air temperature is 18.5°C. The catchment areas of all four localities are composed of shales, sandstones and conglomerates. Na⁺ and Cl⁻ are the dominant ions in each (Timms, 1970). Each is shallow (< 7 m deep) and overflows after heavy rain. The three dams, although not farm dams, are similar to them, in that they are designed to retain most of the water they receive. Ellalong lagoon is natural. Further information on the localities and analytical methods are given elsewhere (Timms, 1970). Fluctuations in salinity were followed from monthly or bimonthly samples for three years, commencing in March 1966. The variations show no distinct seasonal pattern. The maximum and minimum concentrations shown in Table 2 relate to the twelve months when the widest fluctuations were recorded.

TABLE 2
FLUCTUATIONS IN T.D.S. FOR FOUR HUNTER VALLEY
LENTIC LOCALITIES

	T.D.S. in p.p.m.		Percentage fluctuation	Water renewal ratio
	Min.	Max.		
Maitland Power Station Dam	871	1,152	32	4
Abernathy Colliery Dam	153	282	84	19
Richmond Main Colliery Dam	127	325	156	20
Ellalong Lagoon	142	815	474	99

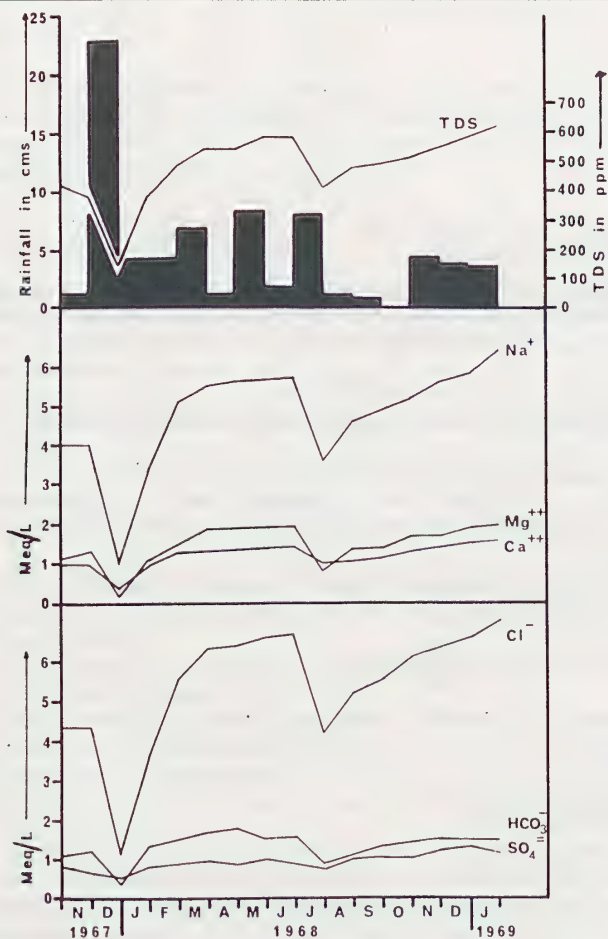


Fig. 1. Fluctuations in rainfall, T.D.S. and concentration of major ions in Ellalong Lagoon.

The mean percentage fluctuation in salinity for the four sites is 187%, which is greater than that so far recorded for Australian fresh waters (Table 1). Yaalon (1964) notes a percentage fluctuation of 120% for a freshwater marsh (< 0.5 m deep) in Israel. The larger fluctuations in this marsh and in the four Hunter Valley sites is associated with their relative

shallowness as compared with that of Mount Gambier lakes, Spencer Gulf Reservoirs and Sydney reservoirs. An increasing number of Australian fresh waters essentially similar to the Hunter Valley localities are coming into existence, and though their fluctuations are considerable, they are not as great as those in athalassic saline waters.

Water renewal can be expected to be an important factor influencing the extent of T.D.S. fluctuations in discrete bodies of fresh water. If the ratio (catchment area) : (surface area) of lake is used as a measure of water renewal (Ravera and Tonolli, 1956), then the correlation between T.D.S. fluctuations and water renewal is significant at the 0.01% level ($r = 0.99$) (Table 2).

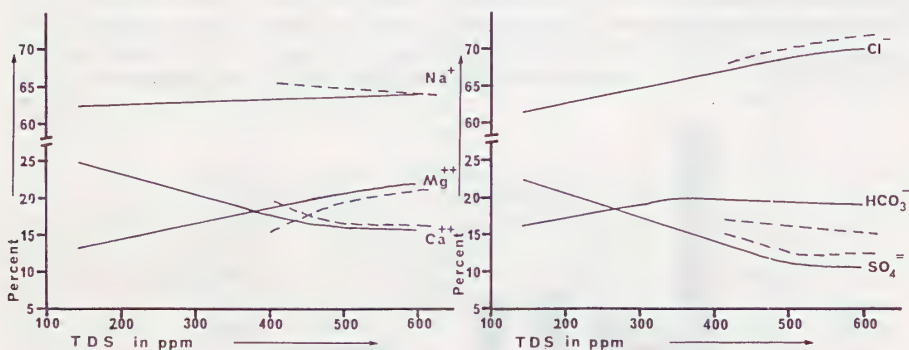


Fig. 2. Variation in ionic proportions with change in T.D.S.. Two periods of T.D.S. concentration are plotted, the first (unbroken line) from January to May 1968, and the second (dashed line) from August 1968 to January 1969.

TABLE 3
CONCENTRATION FACTORS FOR MAJOR IONS IN THREE LAKES

Parameter \ Lake	University pond*	Marsh in Israel [†]	Ellalong Lagoon
T.D.S.	2.3	2.2	5.7
Na^+	2.1	2.3	5.7
Ca^{++}	1.7	1.7	3.5
Mg^{++}	4.7	1.9	8.7
Cl^-	2.5	2.2	5.9
HCO_3^-	2.4	2.1	5.6
$\text{SO}_4^{=}$	—	— 2.3	3.0

* Calculated from Timms (1967).

[†] Calculated from Yaalon (1964).

Fluctuations in the amounts of the major inorganic ions were followed in Ellalong lagoon between November 1967 and January 1969 (Fig. 1). T.D.S. and rainfall are inversely related, the relation being closest in summer because evaporation proceeded most rapidly then. Not all the ion concentrations followed the fluctuations in T.D.S. This led to a change in ionic dominances from $\text{Na} > \text{Ca} > \text{Mg}$ and $\text{Cl}^- > \text{SO}_4^{=} > \text{HCO}_3^-$ to $\text{Na} > \text{Mg} > \text{Ca}$ and $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{=}$ as the water concentrated. These changes are clearly shown in Fig. 2. As the water concentrated, the proportions of sodium and divalent cations remained relatively constant, but among the divalent cations there was a decrease in the relative concentration of Ca^{++} , and an increase in that of Mg^{++} . For the anions the situation is not as clear, but it is evident that the relative concentration of Cl^- increases at the expense of HCO_3^- and $\text{SO}_4^{=}$.

A further method of examining changes in the relative concentrations of major ions is to compare the concentration factors (obtained by dividing the maximum concentration by the minimum concentration) for each (Table 3, column 4). In the main, these factors behave similarly to those in two other studies (Table 3.). In all three, Na^+ , Cl^- and HCO_3^- increase proportionately with increasing T.D.S, Ca^{++} and particularly $\text{SO}_4^{=}$ increase disproportionately while changes in Mg^{++} are variable. Yaalon (1964) explains the lower Ca^{++} concentration rate as being due to precipitation of Ca^{++} as CaCO_3 whereas the decrease in $\text{SO}_4^{=}$ was due to bacterial reduction. Perhaps the latter process occurs in Ellalong Lagoon, but no Ca^{++} could have been lost by precipitation since the solubility product of CaCO_3 was not reached. It is possible that the lower Ca^{++} concentration rate was due to removal of Ca^{++} by organisms. The variability in the Mg^{++} concentration rate in the three localities must, however, remain unexplained, since present data are insufficient.

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NOTES ON LAKE KUTUBU, SOUTHERN HIGHLANDS OF THE TERRITORY OF PAPUA AND NEW GUINEA

by I. A. E. Bayly*, J. Peterson[†] and V. P. St. John[‡]

I INTRODUCTION

Lake Kutubu in Papua lies at an elevation of 808 m among the headwater tributaries of the Kikori River, draining by it to the Gulf of Papua via the Soro and Mubi Rivers. Approximately 19 Km long and nearly 4Km wide at its widest, it is one of the largest lakes in the island of New Guinea. It is located in the Southern Highlands District within the Nipa sub-district (see Ward and Lea, 1970).

According to Sinclair (1969), the lake was first discovered by European man in 1936 when it was spotted by Gurney, Hides and I. Champion whilst making an aerial reconnaissance for the famous journey made later that year by I. Champion and Adamson. The latter were apparently the first Europeans to visit the lake, arriving there on October 21, 1936 (Champion, 1940). In 1937 another patrol walked from the Papuan coast to Kutubu led by C. Champion and Andersen. They established the Kutubu outpost which was used as a base for further exploration until war-time measures caused it to be closed in 1940.

The government returned to Lake Kutubu in 1949 to establish the patrol post, Tage, at the north end of the lake. Supply for Tage was by sea plane. This patrol post was abandoned in 1967 after the establishment of more accessible posts to the north, but the mission at Inu remains. It is situated near the old patrol post and is serviced by the small unofficial airstrip (Moro) on the other side of the lake (Fig. 1).

The mean annual rainfall at Lake Kutubu is 450 cm with an annual average of 281 rain-days. Mean monthly temperatures are between 22°C and 24°C, July and August being cooler than all other months, the averages for which vary by less than 1°C (for more detailed information see C.S.I.R.O. 1965).

II MORPHOMETRY

Echo-sounding traverses were made [by J.P.] at constant speed between shoreline features readily identified in the field and on the air photographs. These positions were later transferred to a 1:50,000 photogrammetric map of the Kutubu area (Australasian Petroleum Company, 1970). The soundings were made in August 1969 with a Koden SR 385 M instrument. The manufacturers specify an accuracy of within 5%, which is greater than the freshwater – seawater adjustment of 3% (International Critical Tables, Vol. 6 (1929), p. 464). The instrument calibration is based on the average velocity of sound in sea-water of average salinity at 12°C.

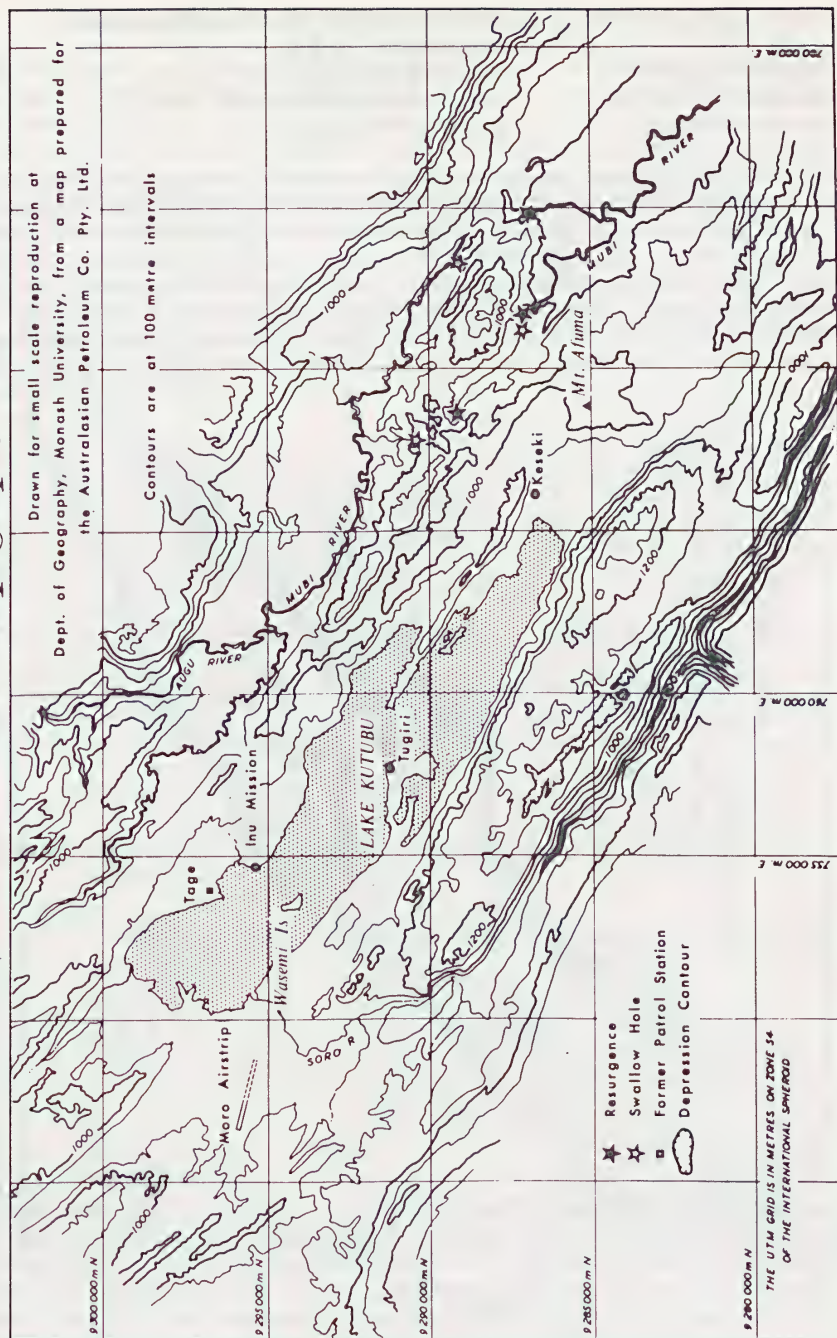
The water of Lake Kutubu is fresh (see below) and the temperature is considerably higher than 12°C (a single surface temperature recording was taken in late August 1969 – this was 24°C). The lake level in August 1969 was some 2 metres below what appeared to be the most common high level. These considerations, together with the probability that the echo-sounding runs did not pass across the deepest part of the lake would account for the fact that the maximum depth recorded did not correspond with the maximum depth obtained by line sounding in 1961 (see below). The 740 m isobath is included on the basis of this line sounding. While there are a number of reasons why the isobathic map (Fig. 2) cannot be considered as hydrographically exact it can be regarded as sufficiently accurate for most limnological purposes.

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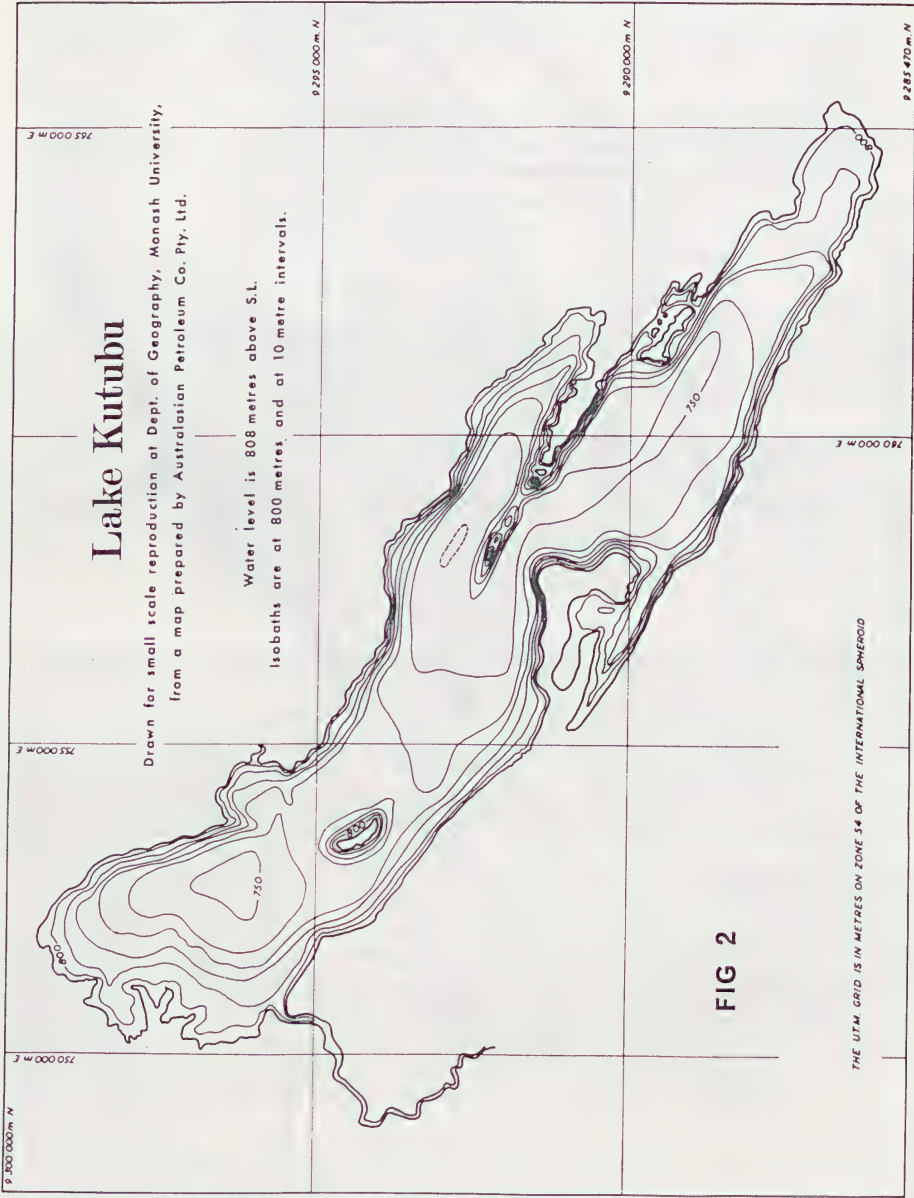
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FIG 1 Lake Kutubu : Topography



The following morphometric parameters were calculated from the isobathic data:

Length 19 Km	Mean breadth 2.66 Km
Volume 1.825 Km ³	Volume development 1.692
Maximum depth ca. 70 m	Mean to maximum depth ratio 0.564
Mean depth 36.12 m	Shoreline development 2.837



III GEOLOGICAL INFLUENCES ON THE FORMATION OF LAKE KUTUBU

The Geological knowledge of the Kutubu area (Fig. 3b) is compounded from work of Australasian Petroleum Company (1961), Herrera and Findlay (1968) and field work by one of us (V.P.St.J.).

The oldest sediments exposed in the Lake Kutubu area are Upper Cretaceous mudstones (Figs. 3a, 3b) which represent the close of (mainly argillaceous) Mesozoic sedimentation in the Southern Highlands Basin (St. John, 1970). During the Lower and Middle Miocene carbonate sedimentation occurred over a broad shelf covering the whole of western Papua. The resulting Darai Limestone has, with restricted local variations, a fairly uniform thickness of about 1000 metres over that region, which includes the Kutubu area. In the Upper Miocene and Pliocene transitional conditions existed over much of the western Papuan shelf, and at Kutubu the limestone is overlain by calcareous mudstone and siltstone, grading upwards into sandstones, siltstones and mudstones with some thin coal seams; the whole section has a thickness of about 1500 m.

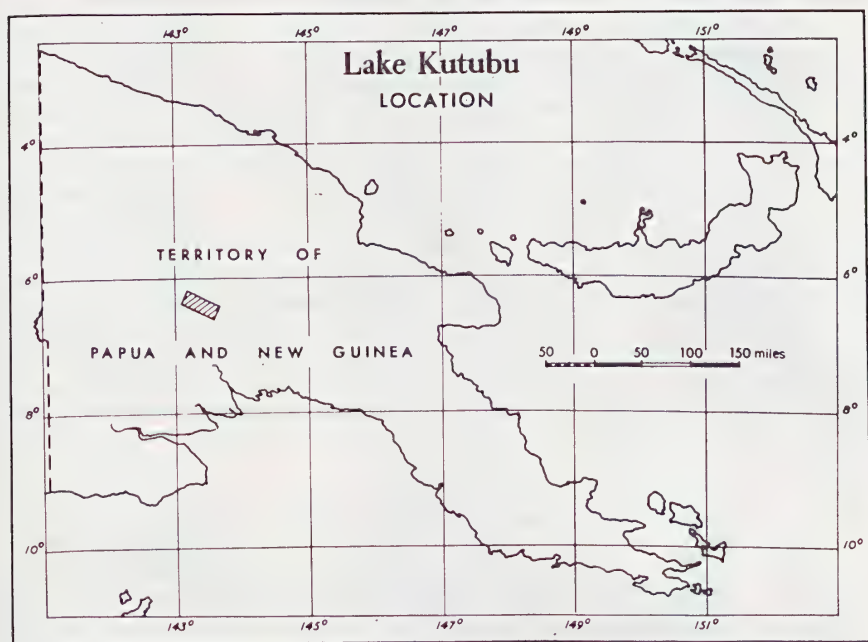


FIG 3A

Towards the end of the Pliocene the quiescent conditions in western Papua terminated with the commencement of orogenic uplift of the central mountain ranges of New Guinea. The upper part of the sedimentary section south of the central orogenic axis was strongly folded about NW-SE axes and overthrust towards the southwest – probably a result of gravity sliding off the central uplift. During the Pleistocene intense vulcanism in western Papua accompanied the late stage of the orogeny. In the Kutubu area this vulcanism is represented by the volcanic apron of Mt. Kerewa to the northwest (Kerewa volcanics, Fig. 3b)

FIG 3B

Lake Kutubu : Geology



Drawn for small scale reproduction at Dept. of Geography, Monash University, from a map prepared for the Australasian Petroleum Co. Pty. Ltd.

and the minor eruptive centre of Mr. Afuma (Fig. 1; Afuma volcanics, Fig. 3b).

Deformation of the Tertiary rocks continued at a reduced rate throughout the Pleistocene, and the interaction of folding and volcanism is responsible for the existing morphology of the area. Drainage on the exposed limestone is sub-surface, except for a few cases of superimposition. Surface drainage follows the trend of folding and a comparison of Fig. 1 and 3b shows that it is largely confined to synclines or under thrust blocks where the impermeable Mio-Pliocene rocks can be expected to overlie the limestone. The limestone topography is governed by the initial folding and modified by solution effects resulting in the formation of areas of pyramid karst. In these conditions it is unlikely that a large body of water could accumulate on the limestone unless it were capped by an impermeable rock.

From the topographic and geological maps it can be seen that Lake Kutubu represents a line of surface drainage which has been blocked by volcanics erupted from Mt. Afuma. However, while the former river valley south of the Papua Thrust was very likely in Plio-Miocene mudstones the continuation of the depression to the north is a result of erosion of the topographically high Papua Anticline limestone. The impermeable lake floor here is apparently made up of eruptives from Mt. Kerewa, which cover the western two-thirds of the depression (Fig. 3b). Present drainage from the lake is via the Soro River (Fig. 1) which cut through the Kutubu Anticline and flows along the Tage Thrust zone.

Of similar shape to, and northeast of Lake Kutubu is a deposit of lacustrine clays (Kagua Clays, Fig. 3b) in a depression marking the site of a former lake, which, like Kutubu, drowned a topography characterised by pyramid karst (Jennings and Bik 1962, called labyrinth karst by Verstappen 1964). However, unlike Kutubu, the pre-lacustrine drainage pattern appears to have been deranged by continuing tectonic uplift rather than volcanism. The depression of the Kagua Clays around Lake Kutubu indicates that here also much of the former lake has become swampland.

Drowned pyramid karst is shown on the isobathic map and is conterminous with the pyramid karst at and behind the shorelines of limestone. The submergence of pyramid karst dates to the time of burial of neighbouring karst by volcanic lavas and debris to form the lake. The buried and drowned topography need not necessarily have been very old, as it has been pointed out by Jennings and Bik (1962) that well developed karst has formed in some parts of New Guinea within the Pleistocene. As mentioned above the volcanics that caused lake formation are Pleistocene so that the lake is probably more than 10,000 years old but is probably less than 0.5 million years old.

IV PROBABLE THERMAL REGIME AND MODE OF CIRCULATION

In 1961 one of us [I.A.E.B.] received an interesting communication from Mr. R. Bucknell who at that time was employed in the Territory of Papua and New Guinea as a fisheries officer by the Department of Agriculture, Stock and Fisheries. In his letter (5.x.1961) Mr. Bucknell commented, "One interesting thing about it [Lake Kutubu] is the fact that about every two years there occurs a phenomenon known as the 'Turning of the Waters'. It appears that water upwells from the depths (72 m max.) and causes extensive mortality of fish. The upwelling water is red in colour . . . We have found only a slight decrease in temperature with depth (about 1.5 degrees C surface to bottom), and a very constant temperature from day to day."

In 1969 another of us [J.P.] heard a very similar account related by the Rev. Murray Rule, a missionary stationed at Lake Kutubu.

Despite the rather circumstantial and anecdotal nature of the evidence it seems quite probable that Lake Kutubu is *oligomictic*. This term was introduced by Hutchinson and Löffler (1956) to refer to tropical lakes of small or moderate area or of very great depth, or in regions of high humidity, in which a very small temperature difference between surface and bottom is normally sufficient to maintain a stable stratification. Such lakes circulate completely only

at rare irregular intervals when abnormally cold or stormy weather occurs. When deep circulation occurs, deoxygenated water containing considerable amounts of hydrogen sulphide are brought to the surface and mass mortality in fish populations results (cf. Bucknell's account). On the other hand the upwelling of deep waters fertilizes the surface waters by greatly increasing the concentration of such nutrients as nitrates and phosphates and as a consequence phytoplankton blooms, often involving blue-green algae, typically develop shortly after the rare event. Beadle (1966) discusses these events with respect to Lake Nkugute, a small crater lake in east Africa. A mass mortality of fish evidently occurred in this lake in July 1956.

With respect to the red colouration mentioned by Bucknell the impression is given that this existed at the time of the upwelling in which case it may well have been caused by coloured anaerobic bacteria. If, on the other hand, the red colouration developed some time after deep waters reached the surface then one might suspect *Oscillatoria rubescens*. Hutchinson (1957:417) mentions the ability of this alga to impart a striking red or purple colouration when hypolimnetic water is carried upwards.

The general climatic conditions, especially the high humidity, obtaining at Lake Kutubu are highly favourable for the establishment of oligomictic circulation. The mean monthly relative humidity at 9.00 AM is 85–90%. At 3.00 PM relative humidity is lower but still lies within the range 70–80% throughout the year (C.S.I.R.O. Aust. 1965). Ruttner (1931) found numerous examples of intensively stratified oligomictic lakes in Indonesia where the relative humidity is usually between 80–90%. He found that the larger lakes of this area had temperature gradients of only 1° to 2°C across the metalimnion. Lake Toba, for example, had a feebly marked metalimnion from 25 m to 50 m and a gentle fall in temperature in the deep water. The total temperature difference was only 2.5°C (23.9° to 26.4°C).

If Lake Kutubu is indeed oligomictic there is no reason to suppose that there is anything at all regular about its periods of circulation. That is, there is no basis for believing that this occurs "about every two years".

It may be noted that the water of Lake Kutubu is quite fresh; a sample collected in August 1969 has a K_{18} of 152 μ mhos/cm.

V PLANKTON

The calanoid copepod *Calameocia ultima* (Brehm) was re-described and first recorded from Lake Kutubu by Bayly (1962) from plankton collections made by Messrs. R. Bucknell and M. Stuart-Fox on October 3, 1961. It was originally described by Brehm (1960) from material collected in Star Mountains region by the Netherlands New Guinea Expedition in 1959. In January 1965 one of us [I.A.E.B.] collected *C. ultima* from a dune lake at Cape Bedford near Cooktown, Queensland. The latter represented only the third record of the species and the first from Australia.

Zooplankton collected from Lake Kutubu in August 1969 again included *C. ultima* as the most numerous form. In addition there were relatively small numbers of a very small cyclopoid copepod belonging to the subgenus *Mesocyclops* (*Mesocyclops*). The latter species was not *M. (M.) leuckarti* (Claus), a common cosmopolitan cyclopoid. A third zooplanktonic species was a small cladoceran with a length of only about 0.4 mm. This species certainly belongs to the family Daphniidae, and at first sight looks like *Ceriodaphnia*, but closer investigation shows that, relative to the size of the animal, quite a large rostrum is present as in *Daphnia*. However, unlike *Daphnia*, there is a definite cervical sinus delimiting the head from the rest of the body. The carapace markings are mainly hexagons, and the central edges of the carapace are quite strongly curved. The generic status of this cladoceran is worthy of further investigation. The only other zooplanktonic species observed was the rotifer *Keratella*.

The most striking aspect of Lake Kutubu zooplankton is the very small size of all species, which are distinctly less than 1.0 mm in length. Perhaps this is a reflection of a high intensity of fish predation (cf. Brooks and Dodson 1965).

Most of the phytoplankton collections made in 1969 contained large amounts of *Botryococcus*. Desmids, however, were the most important group from the viewpoint of taxonomic variety, and were represented by the following genera: *Cosmarium* (sp.), *Staurastrum* (spp. including at least two triradiates, one in the *johnsonii* group, and one of the *limneticum* type), and *Arthrodesmus*. Thomasson (1967) discussed the phytoplankton including desmids from some lakes near Mount Wilhelm in the New Guinea highlands.

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